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Target Description Specifications for the Conduct of Integrated Analysis

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13. ABSTRACT ***(Maximum 200 words)***

The Survivability/Lethality Analysis Directorate (SLAD) represents the combination of three previously separate Army Laboratory Command (LABCOM) components that have led Army survivability, lethality, and vulnerability (SLV) research. SLAD responsibilities are to evaluate the SLV of Army systems against the full spectrum of battlefield threats. The divisions of SLAD conduct extensive simulations and investigations of system SLV performance against conventional ballistic, nuclear, chemical, biological, and electronic threats or targets. One of the technology-based program goals is to develop tools for the analysts to conduct studies that consider combined effects from all battlefield threats. This integrated analysis, we speculate, can be fostered by the three divisions working from a common target description (in BRL-CAD).

The scope of the target description requirements specifies a general target description for integrated analysis across the divisions of SLAD. Discussions are of a general nature and address the specific types of threats for which the different elements of SLAD are responsible and how these specific threats interact (or couple) with the targets. Requirements for target description construction, resolution, and possible changes to the BRL-CAD program are discussed.

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I. INTRODUCTION

The Survivability/Lethality Analysis Directorate (SLAD) represents the combination of three previously separate Army Laboratory Command (LABCOM) components that have led Army survivability, lethality, and vulnerability (SLV) research. This directorate is headquartered at Aberdeen Proving Ground (APG), MD, where the Ballistic Vulnerability/Lethality Division (BVLD) succeeds relevant elements of the Ballistic Research Laboratory (BRL). The Electronic Warfare Division (EWD) (previously known as the Vulnerability Assessment Laboratory), at White Sands Missile Range (WSMR), NM, specializes in electronic warfare (EW) assessments. The Chemical, Biological, Nuclear, and Environmental Effects Division (CBNED) at APG-Edgewood Area (EA), MD, was formed from portions of the former Harry Diamond Laboratories (Adelphi and Woodbridge), the Battlefield Effects Division, WSMR, and the U.S. Army Chemical Research, Development, and Engineering Center (CRDEC).

SLAD responsibilities are to evaluate the SLV of Army systems against the full spectrum of battlefield threats. Field and laboratory assessments of EW threats are EWD's responsibility. The remaining divisions of SLAD conduct extensive simulations and investigations of system SLV performance against conventional ballistic, nuclear, chemical, biological, smoke, obscurants, and atmospheric threat or targets. These three divisions are tasked with applying their simulation, investigation, and analysis capabilities to provide critical support to project managers (PMs), independent evaluators, and decision makers.

2. BACKGROUND

A three-branch symposium was held at APG-EA, MD, on 7, 8, and 9 November 1994. The three branches were the Air Systems Branch (ASB) from BVLD, the Survivability Modeling and Simulation Branch (SMSB) from CBNED, and the Aviation Branch (AB) from EWD. The focus of this symposium was technical integration requirements for the Longbow Apache (LBA) AH-64D. Several actions resulted from this symposium. This report addresses target description specifications for conducting integrated analysis. Representatives from each of the three branches were appointed: Mr. Robert W. Kunkel, Jr., ASB/BVLD; Mr. Richard L. zum Brunnen, SMSB/CBNED; and Mr. Jose G. Reza, AB/EWD.

The scope of the requirements for the target description requirements was moved from that of a single system (i.e., the LBA) to that of the general target description required for integrated analysis across the

divisions of SLAD. Therefore, discussions herein will be of a general nature and will address the specific types of threats for which the different elements of SLAD are responsible.

Another topic which is quite germane to the following discussions is the SLAD vulnerability/lethality (V/L) process structure. This V/L process structure has been documented quite extensively—it is also continuing to evolve. Some of these reports are Deitz (1986); Deitz and Ozolins (1989); Deitz et al. (1990); Klopcic, Starks, and Walbert (1992); Roach (1993); Walbert, Roach, and Burdeshaw (1993); Walbert (1994); Ruth (1994); and zum Brunnen (1995). A revised synopsis of the V/L process structure taken from zum Brunnen (1995) follows.

The basis for the taxonomy of V/L spaces comes from the recognition that V/L analyses pass through distinct levels of information in a precise order. These levels are:

- Level 0. Threat-event states,
- Level 1. Threat-target interaction states, or initial configuration (including initial conditions),
- Level 2. Target-component damage states,
- Level 3. Target-degraded capability states, and
- Level 4. Target-battlefield utility.

The various mission-oriented losses of function (LOF), such as "firepower LOF" and "mobility LOF," can be derived from level 3, target-degraded capability states.

The mappings by which one passes from one level to the next are dependent on different kinds of information at each level. For example, going from level 0 to level 1 (threat-event to threat-target interaction) essentially involves physics; going from level 1 to level 2 (threat-target interaction to target damage) is also based on physics; going from level 2 to level 3 (target damage to degraded capability) requires engineering measurement; and going from level 3 to level 4 (degraded capability to battlefield utility) requires the application of operations research techniques. The process can be shown pictorially, as in Figure 1.

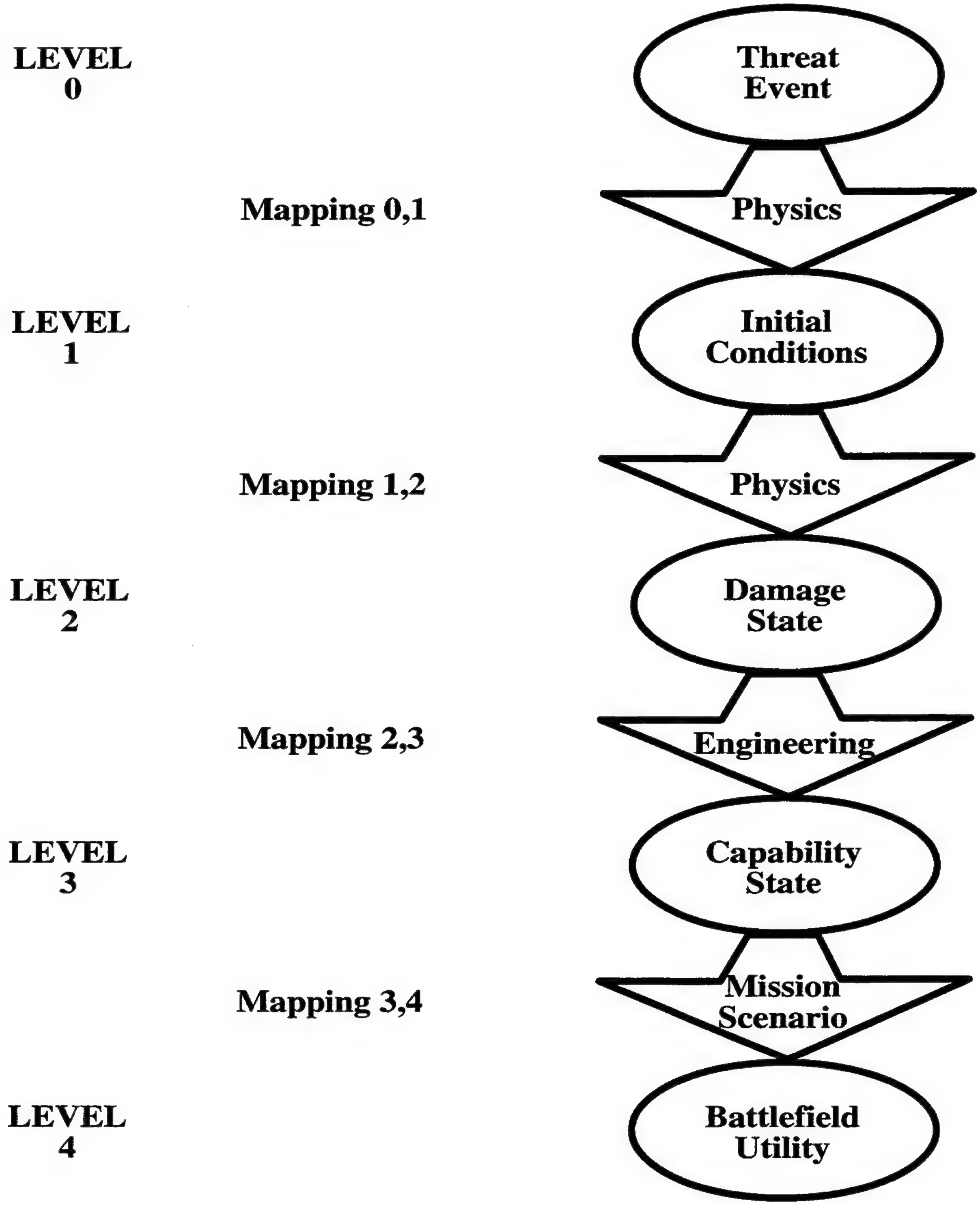

Figure 1. The V/L process structure.

To provide a consistent structure to the taxonomy, the following axioms (assumptions) are given:

1. There are five levels of information making up the vulnerability analysis universe; spaces can be defined at each of these levels.

2. The points in each of the spaces are, in principle, observable and/or measurable.

3. The points in each space are vectors, consisting of one or more elements.

4. There exists mappings from each level to the next, specifically from a point in a space at each level to a corresponding point in a space at the next level.

With these axioms in place:

Definition 1:

1. V/L space 0, or VL0, is the set of all possible threat configurations for event definition.

2. V/L space 1, or VL1, is the set of all possible threats, contained in VL0, and target interaction configurations, previously referred to as the initial conditions. The elements of the vectors in VL1 indicate areas in which the threat interacts with the target.

3. V/L space 2, or VL2, is the set of all possible damage vectors which can result from the threat-target interaction contained in VL1. The elements of the vectors in VL2 indicate the status of all critical components/subsystems.

4. V/L space 3, or VL3, is the set of all possible system capability degradation vectors resulting from the damage states in VL2. The elements of the VL3 vectors indicate degrees of capability (for movement, communication, firepower or—at a finer level of resolution—speed, acceleration, etc.)

5. V/L space 4, or VL4, is the set of all possible battlefield utility vectors resulting from the system capability degradation states in VL3. The elements of the VL4 vectors indicate "LOF" in areas such as mobility, firepower, etc.

Definition 2: The dimension of a space is the number of elements in a vector (point) in that space.

Definition 3: The cardinality of a space is the number of vectors (points) in that space.

Definition 4: The mapping from VL0 to VL1 is denoted O0,1; similarly, the mapping from VL1 to VL2 is denoted by O1,2; the mapping from VL2 to VL3 is denoted by O2,3; and the mapping from VL3 to VL4 is denoted by O3,4.

The V/L process structure provides a framework for an analytical process development. It can be used as a means for identifying knowledge gaps that may then guide possible work to develop a consistent underpinning for future refinements. This taxonomy becomes the guiding structure for analytical model development to ensure proper physical mappings from one state to the next.

It is nearly impossible to discuss what is happening at one level within the process structure without understanding what is happening at another level. For example, when constructing a target description for use in the O1,2 physics mapping (the threat interacting with the target to produce damage states) one cannot divorce oneself from the O2,3 engineering mapping (damaged components to capability states) which uses fault trees. It is impossible for the granularity of the fault trees to be higher than that of the target description. In setting up an analysis, one must initially work backwards up through the process structure to be sure that the metrics which are sought at each level can be achieved with the tools and information that are in hand.

3. TARGET DESCRIPTIONS

3.1. <u>Introduction/Background</u>. This section discusses target description methods and needs. Since the AH-64D is the system of interest in this report, it will be used as the example to highlight the points being made. The geometric computer model of the AH-64D LBA was developed from an existing AH-64A target description created using the constructive solid geometry (CSG) technique. A CSG model consists of simple geometric solids/primitives combined together with Boolean operators to create complex three-dimensional (3-D) objects. In order to update the AH-64A, the CSG facilitated the modification by way of the Ballistic Research Laboratory-Computer Aided Design's (BRL-CAD) Multidevice Graphics EDitor (MGED) (Muuss 1991). MGED is a program, when executed on a suitable computer or

engineering workstation, that provides the visual feedback and operator control necessary to build, modify, and validate highly complex geometric models of tanks, aircraft, communication vans, etc. The Army Research Laboratory (ARL) has been constructing, since 1983, 3-D solid models using the BRL-CAD's MGED for subsequent use in vulnerability analyses. The next few subsections describe the building blocks of the BRL-CAD.

3.2 Primitives. The geometric solids most commonly used in creating a target description are derived from the following four primitives: ARBitrary convex polyhedrons (ARB#) with four to eight vertices, ELLipsoids (ELL), TORii (TOR), and Truncated General Conics (TGC). These solids have specialized menu-driven parameter manipulation associated with it, permitting refined definition of a solid's shape and size. See Ellis (1992) for more details regarding these geometric solids.

3.3 Regions. A geometric solid alone is insufficient to describe the complex shapes encountered in a target description. Combining solids using the three Boolean operators permits the describer to imitate the shape and form of the intricate objects. The Boolean operators are subtraction, intersection, and union. Boolean operations (which are binary in nature) allow two solids to be paired using the indicated Boolean operator, and the result is processed as a new volume to be paired with the next solid and its specified Boolean operator. However, a region can consist of a single solid which is intersected with the entire universe. When Boolean operators are used to define a region, the region becomes a part of the database. A region can be as simple as a single solid or as complicated as hundreds of members combined with Boolean operators.

3.4 Subtraction. Subtracting two solids is all the volume of the first solid less any common volume with the second solid. The subtraction operator (–) signifies subtraction and is useful in hollowing a body, removing an odd-shaped piece of solid, or accounting for edge intersection of walls, plates, piping, or other connected solids. One important restriction of Boolean use that must be accommodated is the convention that regions must begin with a positive body. If an initial solid within a region is associated with the "–" operator, the subtraction is ignored and the union operator is substituted.

3.5 Intersection. The intersection operation (+) combines two solids, saving only their common volume. Unusual shapes can be attained using this operator, and it is commonly used to save a piece of a shell as in, perhaps, a radar dish, or to use only a portion of a standard primitive in a component's

definition. Intersection between two solids having no common points would, of course, be the null set, which is a region having no evaluation potential.

3.6 Union. The concept of union is the converse of intersection. The union operator (u) joins solids so any volume in at least one is part of the resulting volume. The union operation allows several related parts of a single component that overlap or trail one after another to be defined in one region. Usefulness of the union operation is typified in creating wiring harnesses or fuel or hydraulics lines. However, some caution in using the union operator must be exercised. Regions created using this operation add to the evaluation computer run time. For further details and insight into the target description process, see Ellis (1992).

4. THREATS OF CONCERN

4.1 BVLD.

4.1.1 Introduction. BVLD's mission is threefold:

(1) Objectively determine the conventional ballistic SLV of all U.S. Army combat systems,
(2) Provide advice to reduce ballistic vulnerability and enhance the survivability and lethality of these systems, and
(3) Provide timely, accurate, and complete assessments to the systems developers, users, and decision makers.

In order to accomplish their portion of the aforementioned mission, two of the concerns of ASB, BVLD, are the geometric target descriptions and threat characteristics of the threat-target interaction. Although this report covers only air systems, the same needs can be applied to thin-skinned ground targets. The following sections discuss ASB's target description needs, the ballistic threats of interest, and the reasons these are essential to completing its mission.

4.1.2 Armor Piercing (AP) and Armor-Piercing Incendiary (API). AP projectiles are probably the most frequent threat used against a rotary-wing target. ASB has two major concerns when a target is encountered by this type of threat. Some are directly related to the target and some indirectly related. The material type, material density factor, thickness factor, and whether the described component is solid

or hollow (containing fluid) are the ones directly related. Entrance obliquity angle, yaw angle of entering round, and shape of round are the items indirectly related to the target. Note that the following discussion is geared toward metallics, with composites mentioned briefly. Currently, all the penetration equations are geared toward metallics. Penetration equations for composites are under development and will be addressed in a future report. Although composites and ceramics are major concerns in the air community, they are not the focus of this report. The material type of a component is needed for use in penetration equation mechanics. The material density factor is needed to determine fuse functioning, incendiary functioning, spall, breakup/shatter of threat, ricochet, and masking. The thickness factor of a component material is as important in penetration and fusing as it is in engineering. For example, one needs to know how thick the material is to determine residual mass and velocity, as well as know how material reacts to load after damage. Another key factor for target descriptions is how lines (solid or hollow) are modeled. For instance, if one is to evaluate a fuel, hydraulic, or oil line, one would need to know if the line contains a fluid in case fire is an issue. If fire is not a concern in an analysis, it need not be inserted.

An entrance obliquity angle is an important factor when a small projectile encounters a target component. If the target component is metallic, the projectile will usually pierce the component and continue on its path. When a component consists of a composite material, and the obliquity angle is acute, the projectile may get embedded within the fibers that thwart its progress. The yaw angle a threat encounters is important with respect to the penetration equations, jacket stripping, or breakup of the threat, and whether incendiary functioning takes place. If and when the round does function, there are penetration equations for the intact core, broken cores, and broken-broken cores for the respective round. The shape of a projectile/fragment is also a factor in the penetration equations and threat breakup. Projectile shapes are usually in a pointed, blunt nose, and ball configuration, and not all are incendiary. Fragments are usually made of steel and are broken down in the following shape factors:

- Uncontrolled compact,
- Uncontrolled noncompact,
- Controlled diamond shape,
- Preformed sphere,
- Preformed cube, and
- Preformed parallelepiped.

4.1.3 High Explosive (HE) and High-Explosive Incendiary (HEI). HE and HEI are alternate threats used in the aircraft arena. HEI has the same concerns as the API; except for fragments, all the phenomena are different. The blast/overpressure phenomenon requires a target description to have information on the physical and functional nature of the aircraft. The subsystem of interest for a blast analysis is airframe structure. Blast still requires the thickness and mechanical properties of the construction materials. The primary item needs are material type (aluminum, steel, composites, etc.) configuration, location, and dimensions. Shock is defined as a vibration propagating through a solid. Shock also needs the target material type, configuration, location, and dimensions. Fragments are another type of damage mechanism that emerges from a missile. The shape (cube, spherical, long rods, etc.) of the fragment is essential input for the penetration equations. All of this is discussed in more detail in the following sections.

4.1.4 Threat Platforms. A threat platform is a device from which a threat propagator(s) can be fired or launched. A propagator is defined as a device that travels through space or a material. For aircraft, the threat platforms are divided into two categories—nonterminal and terminal. Nonterminal threats do not possess a capability to inflict damage. However, they do support the terminal-threat elements of the enemy by utilizing electronic and/or optical systems. The threat elements consist of detection and early warning devices, target identification, target tracking, and electronic counter countermeasures (ECCM). Their main purpose is to feed information to the terminal-threat units. This is discussed in detail in section 4.3 of this report. Terminal-threat elements have the capability to cause damage to air systems. These are divided into four categories—guns, missile launchers, airborne interceptors, and directed energy devices.

A gun is a device (including any stock, carriage, or attachment) from which projectiles are propelled by the force of an explosive reaction. It includes threats of various sizes, ranging from hand-held small arms to much larger transportable or stationary antiaircraft artillery (AAA). The term projectile is generally used to represent the device carrying the warhead.

A surface launcher is used to launch and guide surface-to-air missiles (SAMs) to an intercept point. SAM equipment varies from a single hand-held launch tube to a semipermanent complex containing numerous trailers, vans, and launch units.

An airborne interceptor is a high-performance, highly maneuverable aircraft designed to engage and destroy airborne targets. Weapon systems employed by the airborne interceptor include air-to-air guns, missiles, and associated equipment for identifying, tracking, and firing the weapons.

Directed energy devices are weapons that produce a beam of electromagnetic radiation (EMR) with intensity sufficient to damage a target. The main focus of this threat is to thermally degrade portions of the target and also have the capacity to overload or blind the various electromagnetic (EM) and optical sensors on the target.

4.1.5 Propagators. Threat propagators, which stem from the previously discussed platforms, are divided into three categories—projectiles, guided missiles, and radiation.

Projectile is defined as an object initially propelled by an applied exterior force and continuing in motion by virtue of its own inertia—as a bullet, bomb, or shell. The propagators usually associated with the gun platform are AAA and small arms. Small arms are the following caliber projectiles, in diameter: 7.62, 12.7, 14.5, and 20 mm. These weapons usually employ visual or optical tracking and are fabricated in differing barrel configurations, usually one to four. A majority of the projectiles in this class are of the ball (B), AP, or API type. Others fired from this platform include the 15.5-mm machine gun, which is also capable of firing an HEI and an incendiary-tracer (I-T) projectile.

AAA denotes the category of guns that fire projectiles greater than 20 mm. The entire group of automatic weapons larger than 12.7 mm is sometimes referred to as antiaircraft (AA) guns. AAA includes the calibers 23, 30, 37, 57, 85, and 100 mm and some greater than 100 mm. The projectiles are either HE, HEI, AP, or API and sometimes carry tracer (T) material. These AAA can be fired from land, air, and sea and may contain either optical and/or radar-tracking devices.

A guided missile is an aerospace vehicle self-propelled through space for the purpose of inflicting damage on a target. A missile consists of a propulsion system, a warhead section, sensor(s), and a guidance system. Without a guidance system, a self-propelled aerospace vehicle would be deemed a rocket. Some missiles have the ability to guide themselves, but others need assistance from the platform's off-board equipment. The two types of missiles that pose a threat to aircraft are SAMs and air-to-air missiles (AAMs) also known as air-intercept missiles (AIMs).

SAMs are those launched from land- or sea-based platforms. They have varying guidance and propulsion systems that influence their launch envelopes relative to their target. They employ many sophisticated electronic counter-countermeasure schemes to enhance the effectiveness. AAMs/AIMs are launched from interceptor aircraft. The primary type of guidance is a homing device that is used because of its weight constraints from the launch platform. The weight constraint only allows the missile to carry relatively small warheads. The preceding two sections were taken from Ball (1985). Please see the reference for more information on threat platforms and propagators, as well as a general survivability discussion of aircraft.

4.2 The CBNED.

4.2.1 Introduction. The mission of CBNED is to characterize through modeling, experiments, and analyses, the survivability of weapon systems and the individual soldier to chemical, biological, obscurants, nuclear, and environmental threats. The threats of concern to CBNED include chemical and biological agents, obscurants, the nuclear effects of thermal, blast, and initial nuclear radiation (INR), and electromagnetic pulse (EMP). In December of 1994, CBNED acquired a new atmospheric branch from the Battlefield Environment Directorate (BED) of ARL. This new branch is responsible for analyzing the effects of weather on weapon systems. Therefore, the threats of concern to CBNED are:

- Chemical Agents,
- Biological Agents,
- Obscurants,
- Nuclear Effects,
  - Thermal,
  - Blast,
  - INR,
  - EMP, and
- Environmental Effects.

4.2.2 Chemical and Biological Agents. In a chemical or biological (CB) analysis, the initial conditions are defined by the agent challenge (either liquid or vapor) that is seen by a battlefield system. This CB challenge is produced by the dissemination, diffusion, and transport of the agent by the local meteorology. The dispersion of a CB agent goes through four phases in its evolution (shown in Figure 2, see CRDEC[1986]).

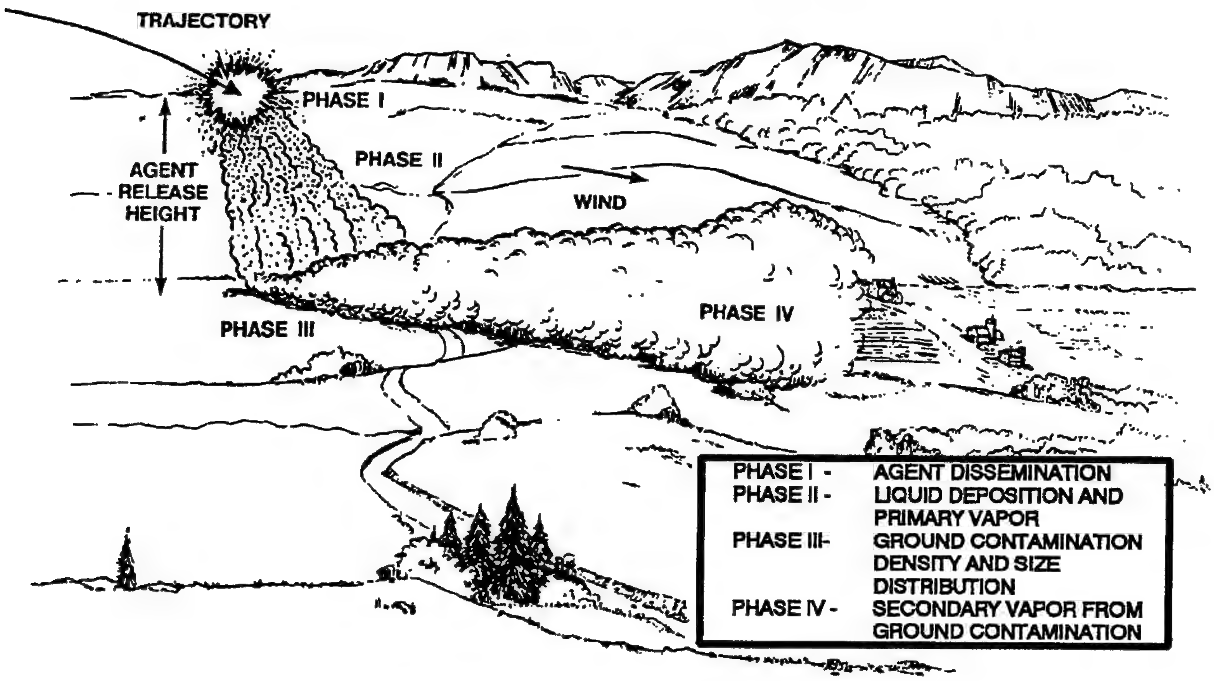

Figure 2. The four phases of chemical-cloud evolution.

Some of the classes of CB agents of concern to CBNED include nerve, blister, blood, choking, bacteria, pathogens, and toxins. The delivery systems for the agents may include (but are not limited to) artillery, bombs, bomblets, rockets, missiles, spray systems, and covert means.

(1) *Phase I - Agent Dissemination.* The initial conditions in a CB scenario are dependent upon the physical characteristics of the threat munition (i.e., munition type, agent fill, etc.) and how the disseminated agent interacts with the local meteorology after dispersion. The munition type determines the method of dissemination (i.e., explosive, base ejection, stripping the warhead skin, ram air, etc.). The method of dissemination and the type of agent determine the droplet size distribution and the ratio of vapor to liquid in the initial agent cloud. The CB cloud generators (i.e., VLSTRACK, PACCE, NUSSE4, etc.) have specific inputs that characterize the agent cloud resulting from the dispersion.

(2) *Phase II - Liquid Deposition and Primary Vapor.* In this phase, the liquid droplets which make up the embryonic CB cloud fall due to gravitational settling and are transported downwind by the local

meteorology. During this settling and transport, liquid from the droplets may be evaporating. This is dependent upon droplet composition and the local meteorological conditions. The vapor that is generated during this phase, as well as the vapor that is set by the vapor/liquid split input variable, is termed "primary" vapor. This is vapor which is generated by either the initial source configuration or from airborne droplets. Depending upon the conditions, many of the falling droplets never reach the ground, where this phase ends.

(3) *Phase III - Ground Contamination Density and Size Distribution.* In this phase, the falling droplets are impacting the surface strata. As the droplets approach the ground—the largest are near the function point—and as one moves downwind, the drop size decreases. This is a function of gravitational settling and the downwind transport. The product of droplet volume, agent density, and the number of drops over a specific area yields the contamination density for that area. The falling drops are the liquid threat to the battlefield systems. The CB agent will interact very differently with the multiple military surfaces.

(4) *Phase IV - Secondary Vapor From Ground Contamination.* Once the liquid droplets reach the ground, the droplets spread and the surface area from which agent can evaporate changes drastically. In this phase, the change in the evaporation and the sink rates of the agent are the driving factors. The vapor generated during this phase is termed "secondary" vapor. This vapor and the vapor generated in Phases I and II are the vapor threats to the battlefield systems.

There is an extremely heavy dependence upon time in these four phases. The more time the agent spends in the air, the further downwind it may be transported and the further cross wind it diffuses. Time is also a major factor in the evaporation physics of the agent.

It should also be noted that the CB threat evolves and changes over time. This is contrary to the time frame of the classical ballistic event. When dealing with a point-detonating HE munition, the initial conditions are formed nearly instantaneously.

4.2.3 Obscurants. Obscurants is used here to represent classic visual "smokes" (fog oil, white phosphorous [WP], and pyrotechnic mixtures) as well as more recent bispectral and millimeter-wave (MMW) defeating materials (metal and graphite particles, coated and plain fibers). These materials can be disseminated by multiple means—artillery, rockets, smoke pots, grenades, vehicle engine exhaust

systems (VEESS), and large-area generators. Two principal effects of threat obscurants are (1) performance degradation of smart sensors and weapons due to absorption, scatter, or emissive effects on received radiation and (2) system degradation due to accumulation of obscurant materials on vulnerable components (e.g., optics, external connectors, seals, and gaskets).

Obscurant materials (visual and bispectral) show transport and diffusion characteristics similar to those of chemical agents. MMW materials have different transport properties because the particles are larger and have large length-to-diameter ratios. These materials are often modeled like chemical agents with average concentration-pathlength products reported for lines of sight through a Gaussian plume. These values were adequate for estimating material deposition rates and totals, and for providing average attenuation values on lines of sight to a specific target. The obscurants can also produce effects on target acquisition through the effects of turbulent cells in the cloud on radiation transmitted to the receiving sensors.

4.2.4 Nuclear. Much of the discussion on the nuclear environments, which follows, was taken verbatim from Moffett and Alderson (1987).

In a nuclear explosion, an enormous amount of energy is released in less than 1 millionth of a second. A typical nuclear blast releases the equivalent energy of thousands to millions of tons of TNT and reaches a temperature of tens of millions of degrees Celsius. Nuclear weapons have a tremendous yield-to-weight ratio. Pound for pound, nuclear weapons are 10 to a 100 million times more powerful than conventional weapons. This tremendous energy release results from the splitting of very heavy atoms by the process known as fission, or the combining of very light atoms in a process known as fusion.

Weapon output varies with size and yield and with the actual height of burst. Typical energy output from relatively low-altitude nuclear airbursts can be broken down as follows:

Thermal radiation	35%
Blast and shock	50%
INR	5%
Residual nuclear radiation	10%.

The distribution can also vary with weapon design. For weapons of an enhanced radiation design, about 30% of the output is in the form of INR; blast, thermal, and residual radiation are all reduced.

The tremendous amount of energy released as x-rays is quickly absorbed within a few meters by the surrounding air. (Since these x-rays are absorbed at such short distances and generate the secondary environments of interest, they are not listed as an aforementioned output.) This absorption generates the extremely hot and incandescent spherical mass of air and gaseous weapon debris known as the fireball. The fireball expands and rises, emitting the thermal radiation that represents about a third of the energy release and creating a blast and shock front that carries about half of the energy.

The INR is that radiation that occurs within the first minute following the explosion. It includes the neutrons and gamma rays released during the explosion, the gamma rays emitted by the fission products and radioactive debris, and the gamma ray as products of neutron and gamma ray interactions (mostly with the soil). The residual nuclear radiation is that delayed nuclear radiation generated by the fission process after the first minute following the explosion. This is also known as fallout or rainout.

(1) *Thermal.* The thermal pulse consists of visible, infrared (IR), and ultraviolet radiation emitted from the fireball. This energy is similar to that delivered by the sun. About a third of the energy from an air burst is in the form of thermal radiation. This large percentage of heat energy released in a very short time is another significant difference between a nuclear explosion and a conventional HE detonation. HEs also produce less heat.

Thermal radiation has two forms. About 1% of the thermal emission is in the form of a short-lived initial pulse of mainly ultraviolet radiation that is quickly attenuated by the atmosphere. The first pulse is of no significant consequence to most types of equipment. The rest of the thermal emission is in the form of a secondary pulse of visible and IR light that can last several seconds; longer for the larger weapon yields (as little as a second for about 10 kt, to about 5 s for a 300-kt explosion).

The amount of thermal pulse transmitted through space is very dependent on atmospheric conditions and the atmosphere's absorption, reflection, and scattering properties. These are determined by such factors as rain, industrial haze, dust clouds, and snow cover. For example, a thermal level of 5 cal/cm^2 will be experienced at about 2,300 m from a 10-kt burst on a very clear day. If there is fog, this level

is transmitted about 1,500 m. Obstructions such as terrain, buildings, and forests also modify this environment.

(2) *Blast.* X-rays from an air burst quickly heat the surrounding air, creating a fireball. Intensely hot, extremely high-pressure gas in the fireball expands rapidly, pushing in front of it a wave of shocked air—a blast wave. This wave is characterized by a sudden increase in pressure at the blast front, a gradual decrease in pressure to the predetonation (atmospheric) air pressure, a further decrease in pressure below atmospheric due to the overexpansion of the hot compressed gases, and an eventual return to the atmospheric pressure (see Figure 3).

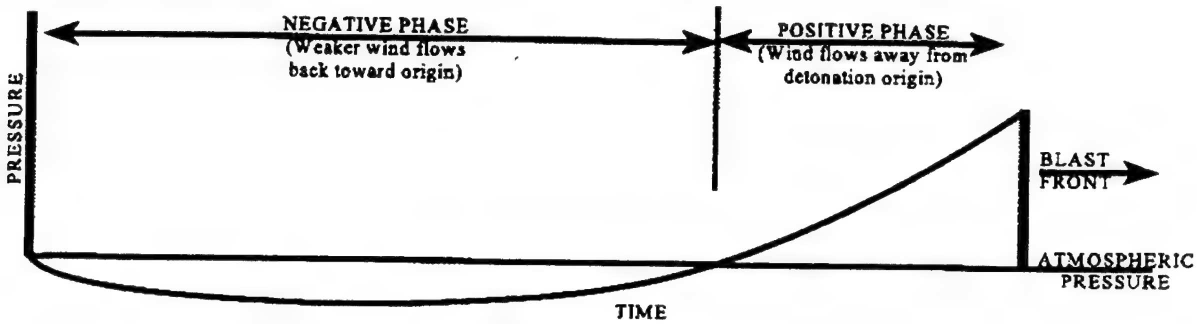

Figure 3. Blast wave at a given location.

Blast produced by conventional explosives is just like blast produced by nuclear weapons with the exception that most nuclear weapons are of greater yield. The larger yields deliver higher pressures, and associated winds, at greater distances. Duration of the pressure and wind at a given distance is also a function of yield—the larger the yield, the longer the duration.

Referring to Figure 3, the overpressure (above atmospheric) portion of the blast wave is called the positive phase. The length of this phase is the length of time required for it to pass a given point. While the blast wave is expanding radially outward, the original hot compressed gas is cooling, which results in a reduced pressure in the vicinity of the origin. The overexpansion and resultant reverse flow causes the local pressure to fall below, and then return to, atmospheric pressure. This portion of the blast wave is referred to as the negative phase.

In order to illustrate the magnitude and duration of some of the parameters described previously, let us look at some blast waves produced by the detonation of a 20-kt nuclear surface blast. Table 1 shows examples where the maximum static overpressures would be 1, 5, and 15 psi.

Table 1. Blast Wave Parameters - 20-kt Surface Burst

Maximum static overpressure (psi)	1.0	5.0	15.0
Maximum dynamic overpressure (psi)	0.02	0.7	4.8
Time from detonation to blast wave arrival (s)	16.0	5.0	1.9
Positive phase duration (s)	1.4	0.9	0.6
Maximum wind speed (mph)	36.0	160.0	400.0

Static and dynamic overpressures are two of the most significant blast parameters when designing survivable equipment. Peak pressure and duration, especially the positive phase duration, are both important. Differential pressure loading tends to crush and break equipment. Overturning and tumbling of equipment is, to a great extent, the result of a peak static pressure combined with the dynamic pressure impulse. Dynamic pressure impulse, which is the total dynamic pressure delivered during the positive phase, is the blast parameter that imparts drag loads and is so dominant in moving and overturning equipment (especially when weapon yields exceed 2–3 kt).

(3) *INR*. INR is marked by the release of gamma rays and neutrons and their atomic interactions. This environment is unique to nuclear weapons. It cannot be seen, heard, felt, smelled, or tasted.

Gamma rays are similar to x-rays but are of higher energy, which enables them to penetrate much greater distances in materials. These highly penetrating gamma rays interact with the electrons and atoms in materials and components, commonly knocking off electrons, leaving behind an ionized atom.

Neutrons are energetic, unchanged particles that can travel long distances in the atmosphere. They also easily penetrate many materials and interact with components. While able to ionize atoms, they can interact with the nucleus of the atom by two additional mechanisms. The first is scattering, during which the neutron loses energy, moves in a new direction, and, in the process, displaces the nucleus, sometimes causing it to emit gamma radiation. The second mechanism is absorption, in which the neutron is captured in the nucleus. In most cases, the nucleus becomes unstable and re-emits alpha or beta particles and gamma radiation.

(4) *EMP*. When a nuclear detonation occurs at a very high altitude, the only output of concern to our tactical land systems is a phenomena known as high-altitude EMP. High-altitude EMP is a radiating pulse of EM energy generated as the gamma rays travel toward the earth and interact with the earth's magnetic field. This interaction generates a downward moving EM wave. The area in which the EMP fields are generated is called the EMP source region.

Weapons detonated hundreds of kilometers up can generate high-altitude EMP, affecting a continent. And, for larger yield weapons, greater than 500 kt, the strengths of this pulse can be very large, even over these very wide ranges.

Since gamma rays and the EMP waves travel in straight lines, any systems within lines of sight of the burst are exposed to the environment created by them in the vicinity of the system. This means that all systems out to the tangent to the earth's surface are exposed in a very large surface area.

Within the height-of-burst coverage areas, field strengths with a peak value on the order of 50,000 V/m, or 50 kV/m, can be experienced but are not spatially uniform. Because of system configuration uncertainties, system assessments and hardening are almost always based on a conservative assumption that the system will be exposed to a worst-case EMP environment.

Since the rise time of an EMP pulse can be on the order of nanoseconds (billionths of a second), most of the energy is delivered within a microsecond (one millionth of a second) or less. This time span corresponds to frequencies from direct current to above 100 million cycles/second, or 100 MHz. This wide-area coverage, large amplitude, and broad-frequency coverage accounts for high-altitude EMP being a widely recognized threat environment.

High-altitude EMP is only one of several EM environments of concern to equipment. It has features in common with lighting and with electromagnetic interference (EMI), electromagnetic capability (EMC), and radio frequency (RF) sources. But there are clear distinctions. While lighting strokes may induce more total energy than EMP, EMP has a much faster rise time, and it, therefore, extends to higher frequencies. A significant portion of EMP energy is in the very-high frequency (VHF) and the ultrahigh frequency (UHF) ranges, whereas lighting is more in the high-frequency (HF) range. While EMP extends over much of the same frequencies as EMC/EMI, it is usually at higher energy levels and propagates over

vastly greater distances. EMC/EMI avoidance can be achieved by increasing the distance from the source. As we have seen, this is not practical for high-altitude EMP.

An EMP can also occur from a nuclear burst in the earth's atmosphere. For example, tactical bursts near the surface of the earth can create complex EM source regions with peak amplitudes up to 1,000 kV/m, but they only extend about as far as the other environments. The radiated field from this source region, which has strengths up to 10 kV/m, is also confined to the local area—on the order of 10 km in radius.

The EMP from an air burst is similar to surface-burst EMP and can extend to ranges from 2 to 30 km. However, its radiated region field strengths are smaller—only a few hundred volts/meter.

System-generated electromagnetic pulse (SGEMP) is not produced by the atmosphere and the earth's magnetic field, rather it is produced by nuclear radiation, particularly x-rays and gamma rays interacting directly with the system itself. SGEMP is a significant problem for systems outside the earth's atmosphere, where the x-ray environment can propagate over long distances. At or near the earth's surface, x-rays do not propagate very far, but gamma rays do. However, gamma rays are not as efficient in the production of an SGEMP. SGEMP is considered to be a problem only for equipment in large electronic signal shelters or enclosures.

4.3 EWD.

4.3.1 Mission. The EWD mission is to determine the EW vulnerability of U.S. Army and foreign systems. This mission is performed in several EWD branches in which conventional in-band active and passive EMC are addressed.

Table 2 lists the EW threat to the survivability of the Longbow System (Apache D and Longbow Modular Missile System [LBMMS]), not those countermeasures (CM) affecting system lethality. We did not consider those EW CM which affect missile performance or the targeting capability of Apache D sensors. As an example, we did consider a laser which might "blow holes" in the fire control radar (FCR) radome (physical damage) but not a jammer negating FCR effectiveness (sensor performance).

Table 2. EW CM Affecting Longbow Survivability

Potential Adversary EW CM	Possible Effect
Battlefield radio frequency (RF) emitters	Degrade/disable electronics
High-power microwave (HPM), ultrawide ban	Degrade/disable electronics
Electronic support measures (ESM)/radar warning receiver (RWR)/electronic intelligence (ELINT) receiver	RF, microwave, MMW detection
Acoustic receiver	Apache D detection
High-power laser (HPL), designators, laser range finders	Damage to Apache D, LBMMS, personnel, sensors
Air defense unit (ADU), battlefield radars, forward-looking infrared sensor (FLIRS)	Detection Apache radar cross section (RCS)/IR signal
Communication jammer	Degradation command/control
Gunner's primary sight (GPS) jammer	Degradation navigation aid, situation awareness
Battlefield Combat Identification System (BCIS)/identification, friend or foe (IFF) jammer	Degrade combat identification (ID)
Virus injection into software	Apache D/LBMMS performance
Counter survivability suite	Negate protection of suite

The EW CM shown in Table 2 are generic and appear to be technologically viable during the life span of the helicopter and missile. They may not be feasible for all adversaries, and the actual threat will vary widely between countries. There is a gray area between survivability and lethality (system effectiveness) since some CM affecting effectiveness may also degrade survivability. An example is a conformal radar-absorbing/scattering net spread upon a target vehicle. It will degrade detection, hence lethality, but by potentially increasing the exposure time of the helicopter to enemy fire will also affect survivability. Such considerations are not included in Table 2.

4.3.2 SEMI/HPM. SEMI is an out-of-band, body-mode coupling, radio-frequency countermeasure (RFCM) jamming technique that is threat driven (hostile intent to degrade system performance). The SEMI RFCM techniques are those an adversary would use if he intentionally wanted to adversely affect the performance of a weapon system. HPM is a high-power version of the SEMI RFCM technique. Traditionally, HPM was focused on inducing damage to electronic components; however, over the last

10 yr, that has changed or evolved to inducing high-power electronic upset. Whereas SEMI is concerned with inducing system upset at tens of volts/meter, HPM typically looks at values around 1 kV/m. The following SEMI discussion is thoroughly appropriate and relevant to HPM.

Figure 4 illustrates the SEMI engagement scenario. Figure 4 shows an enemy aircraft being tracked by a U.S. missile. An enemy SEMI jammer is deployed in the area and is targeting the missile. With a priori knowledge about the missile's operational parameters, the jammer can be configured to optimize its ability to induce missile performance degradation.

Figure 5 depicts the coupling mechanisms of SEMI or out-of-band, body-mode coupling. Incident RF energy (usually at a frequency whose wavelength is related to the weapon's physical dimensions) induces currents on the weapon's airframe. These currents generate RF energy in the weapon's interior via interaction with the airframe discontinuities such as fin slots and open seeker domes. Once inside, the RF energy produces currents on system wiring that are conducted to semiconductor junctions where rectification and detection takes place. The resulting spurious (SEMI) signals resemble the envelope of incident RF waveform (modulation). The SEMI signals compete with legitimate system signals and cause observable interference on circuits processing normal weapon functions, particularly if the incident waveform has the same or similar characteristics to those that are inherent in weapon-signal processing (i.e., spin speed, clock frequencies, etc.). The potential for this extraneous RF energy to cause weapon performance degradation depends on the amplitude ratio of RFCM-induced signals to legitimate target signals. At this point, several things can happen:

- A true target may be masked,
- A false target may be recognized, or
- Erroneous signals may be sent to the control surfaces resulting in a missile that is, in essence, "out of control."

SEMI methodology and investigations enable us to determine the RFCM parameters that render a system most susceptible. Susceptibility curves vs. frequency and threshold power density are generated and represent the system's most susceptible profile (i.e., at the most effective polarization, aspect angle, modulations, etc.).

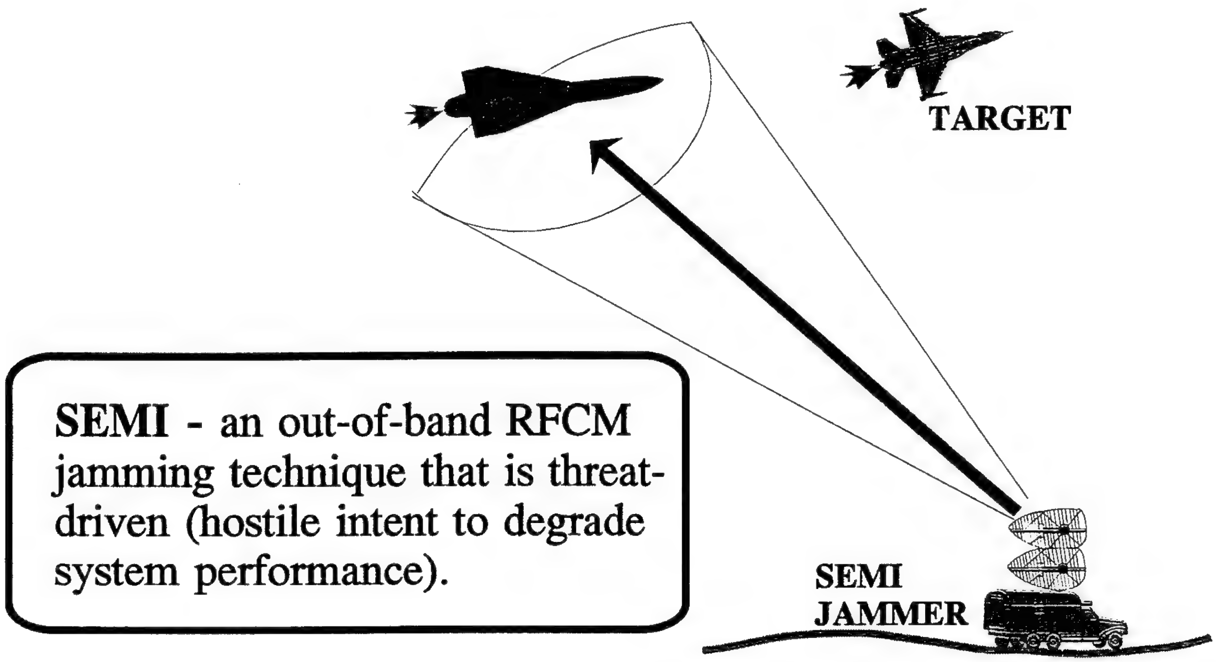

Figure 4. SEMI engagement scenario.

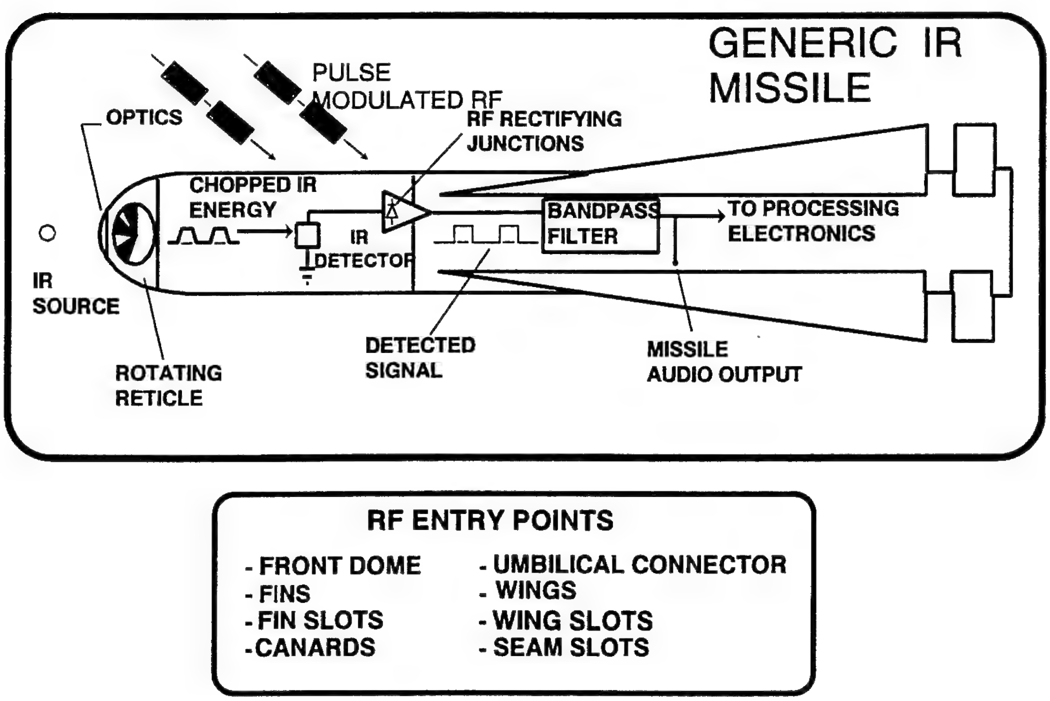

Figure 5. SEMI phenomenology.

The Army SEMI-vulnerability assessment program has continued since its inception to assure that its weapon/communication electronics (CE) systems will perform their intended missions in a severe EW battlefield environment. Over the years, SEMI-vulnerability assessments have been conducted on:

- RF, electro-optical (EO)/IR weapons systems,
- Helicopters,
- Artillery/mortar fuzes,
- Tanks,
- Foreign missile systems, and
- RPV/FLIRS.

The results of U.S. Army system investigations have provided PMs comprehensive out-of-band RFCM susceptibility/vulnerability data and corresponding ECCM recommendations to reduce or eliminate vulnerabilities to SEMI-induced performance degradation. Foreign missile system investigations have provided susceptibility data to assess the feasibility of, and specifications for, SEMI jammers that can exploit susceptibilities/vulnerabilities found.

The objectives of the SEMI program are to:

- Determine the vulnerability of U.S. Army weapon/CE systems to low-level out-of-band RFCMs,
- Identify ECCM fixes to reduce susceptibility/vulnerability,
- Make timely ECCM-fix recommendations to project managers' offices (PMOs) for cost-effective system hardening, and
- Evaluate the effectiveness of the ECCM fixes if they are implemented.

4.3.3 Methodology. SEMI methodology consists basically of conducting the investigations in the following phases:

- Theoretical analyses,
- Laboratory investigations,
- Anechoic-chamber RFCM effects measurements,
- Simulations,

- Tactical environment assessments, and, if necessary,
- An ECCM-fix/evaluation effort.

5. INTERACTION OF THREATS WITH THE TARGET DESCRIPTION

5.1 BVLD. In terms of the BVLD V/L taxonomy, specifically at Level 1, the target description provides background information. Ideally, the target description should emulate the actual target, but because of time constraints and intelligence voids, the target descriptions often suffer in level of detail. It is at the O1,2 mapping where one would question the requirements for a target description. The requirements for the ballistic range of threats are based on the threat-target interaction geometry. Therefore, when determining the issues required for a target, one has to understand the "what" and the "how" of the threat-target interaction as well as the algorithm used to assess the vulnerability. The "what" refers to the type of threat (AP, fragments, HE, etc.) that the target (ground or air) encounters. The "how" refers to the damage mechanisms employed by the threat (i.e., hit-to-kill, proximity fuzing, etc.). Also of concern are the ways in which the threats interact with given material and material configurations. First, the interaction between a metal and the threat could cause a spark, which could ignite atomized fuel. If a threat enters a target that consists of composite material, the reaction will be different.

For example, with material configuration, if one is calculating the residual mass and residual velocity of a threat as it passes through a component, as some algorithms do, one needs to model the component as a hollow box with the appropriate material type, density, and thickness factor and not just a solid box with an "adjusted" density factor to account for the component being hollow. The reason for this is the subsequent damage from the interaction. In the case of a hollow component, the concerns could be as follows: Is there fluid inside the component; Was there spall from the component; Was there any other solid components inside, such as circuit boards? Solid components will not give a true spall pattern, and also do not allow the use of fluids inside.

Another example would be the level of exterior detail needed for a radar study as opposed to a ballistic study. With a radar-vulnerability study, one needs to be extremely concerned with objects that emit a signature, whereas with a ballistic study one's primary focus is not the shape but the properties of the component material.

5.2 CBNED.

5.2.1 Chemical and Biological Agents. The intended target when CB agents are employed is generally personnel. Chemicals can also be used for harassment. If an enemy keeps a portion of the battlefield contaminated, personnel either have to avoid the area or wear the mission-oriented protective posture (MOPP) gear. MOPP adds potential for heat-stress casualties.

As the CB-agent clouds are transported by the local meteorology, these clouds engulf and infiltrate the target. Liquid and solid agents impinge upon exterior and interior surfaces of the target. The agents can have detrimental effects on the materials of which the contaminated surfaces are composed. Chemical reactions between agent and materials result in changed physical properties of the materials. For example, mustard (HD) causes a 25–40% loss of tensile strength in some elastomers.

Another example is an experiment of a polycarbonate plastic vs. HD and thickened Soman (TGD). Two contamination densities (8 and 80 g/m^2) were used with exposure times of up to 24 hr. The agents had no significant effects on the tensile strength, elongation, modulus of elasticity, hardness, and toughness of the polycarbonate plastic. There were, however, significant changes in light transmittance. This was reduced by more than 50%, the haze exceeded 85%, and the surface of the material was crazed (HD dissolved the surface). This example serves to demonstrate that using polycarbonate as a lens may be a significant issue.

5.2.2 Obscurants. The result of friendly forces encountering a threat obscurant or smoke on the battlefield is degradation of one's sensors and target-acquisition devices. For example, fog oil and WP affect the near IR through the ultraviolet wavelengths. WP is also somewhat effective in the far-IR region. The far IR through the ultraviolet are effected by carbon, brass, and dust.

Obscurants not only affect the various signatures of targets, but they may also cause degradation of materials within the target. The effect of a vehicle ingesting dust or carbon into its engine could be quite catastrophic. The impinging of brass filaments on a circuit board could effectively "kill" a piece of equipment.

Obscurants interact with the receiving sensor or weapon system in multiple ways. The materials can cause degradation through three principal mechanisms. Attenuation is the most common effect, and is

usually cited when discussing obscurant effects. This effect attenuates the signal received by the sensor through absorption and scattering in the obscurant. Scattering can affect laser systems and is an important visual and near-IR defeat mechanism. It can also affect MMW bands. This mechanism involves reflection off particles in the obscurant cloud. Attenuation and scatter effects are dependent on microturbulence effects within the cloud, changes in the local wind field, and changes in solar-radiation load on the terrain. Radiance affects the IR bands. Radiance introduces additional clutter, by providing more "hot spots" or warm areas in a sensor's field of view. This can affect target selection, acquisition, and tracking.

5.2.3 Nuclear. For survivability considerations, the arrival times of the different environments are critical to systems response. The environments fall into three general time frames. First, are those with nearly instantaneous arrival (after detonation); second, those arriving within the first few seconds to minutes; and third, those typically extend from minutes to hours or even days.

The exact arrival times and duration of these environments vary with weapon yield, atmospheric conditions, and the distance from the burst point. Note, however, that each effect arrives as a separate, distinct pulse.

The gamma radiation and EMP travel at the speed of light and, thus, arrive almost immediately after detonation. Although neutrons are also released during the burst, they travel at slower velocity, depending upon their kinetic energy (KE) and lose even more energy in atmospheric interactions. These neutron interactions and fission and debris products continue to release delayed gammas.

While thermal radiation also travels at the speed of light, it is a product of the fireball, which takes time to form. The airblast is also generated by the fireball, but only travels near the speed of sound. This assures that essentially all of the thermal pulse arrives before the blast. This sequence in the arrival of these environments creates conditions for other effects. The deposition of a large amount of heat in a short period of time can alter and weaken an object, making it more susceptible to the airblast that follows.

(1) *Thermal.* The initial ultraviolet radiation does not cause significant damage to most systems. The other 99%, the visible and IR thermal radiation can quickly deposit a large amount of heat energy, causing very high surface temperatures that can produce:

- Melting of materials such as aluminum,
- Charring of surface coatings such as paints or insulation,
- Ignition of combustible organic substances (toxic by-products may be released in some of these reactions),
- Debonding of laminates,
- Optical obscuration,
- Weak or highly stressed structures at points of severe temperature gradients,
- Transfer of heat to vulnerable internal components,
- Degradation of a material's properties, and
- Secondary fires in surrounding materials such as vegetation or structures which can damage both equipment and personnel (secondary fires were responsible for much of the damage at Hiroshima and Nagasaki).

Also, recall that the thermal pulse arrives shortly before the airblast and can cause a significant temperature rise in poor thermal-conducting materials such as plastics and fiberglass and in thin-skinned metal enclosures such as missiles. Most materials degrade dramatically after exposure to high temperature, depending on the material, thickness, and color, and may be more vulnerable to a subsequent airblast if, for example, skin strength and stiffness are reduced.

Generally, hardened equipment can survive levels ranging from 30 to about 100 cal/cm^2. Survival above this level requires the use of some special materials and hardening methods. However, in some instances, such as a hardened C3 shelter, thermal survival levels can be much higher (about 170 cal/cm^2).

For comparison, the 50% level for second-degree burns to bare skin occurs at about 3–6 cal/cm^2; under the battle-dress uniform, second-degree burns occur at about 15 cal/cm^2; and for soldiers with the battle-dress overgarment over the battle-dress uniform, second-degree burns occur at about 48 cal/cm^2.

(2) *Blast.* Typically, when an object is struck by a blast wave, pressure on the side of the object facing the detonation point is increased above the incident value by reflection, and a local loading of short duration is delivered. This initial loading delivers a hammer-like blow that can cause the object to experience shock and vibration that can be quite damaging to electronic or mechanical components. The reflected pressure pulse can also be the primary damage mechanism for structural items such as panels, walls, and frames. These elements are typically vulnerable to such short duration loading because of the

high natural frequencies of many structures. As the blast wave continues to engulf box-like objects, leeward and internal surfaces (if the object is not solid) may yet be at ambient atmospheric pressure, which can result in differential pressures that tend to crush or deform panels that are not facing the blast.

Dynamic pressure impulse (high-velocity wind during the positive phase) is also an important part of the blast, especially when dealing with large explosions like those produced by nuclear weapons. The wind continues to deliver drag loads to an object for a period of time after shock-front engulfment. Duration of the drag loading is dependent upon the size (yield) of the weapon. Individual components, as well as the whole object, that were started in motion during the diffraction phase (shock-front engulfment) can be further moved during this drag phase. The maximum speed of the wind associated with a blast can exceed that of a large hurricane. For example, at a range where the peak static (side-on) overpressure would be 10 psi (720 m from a 10-kt low-air burst), the maximum wind speed would be approximately 300 mph. The ripping and tearing of components, and the whole body translations, overturning or tumbling of equipment can be greatly influenced by the velocity and duration of such wind.

Damage threshold levels vary with yield and equipment orientation to the blast and other factors. At smaller yields, it takes a higher overpressure to overturn vehicles than at larger yields due to the shorter duration of the associated blast waves. The various yields that could be deployed on a tactical battlefield help explain the variance in damage thresholds that can be seen (especially for equipment sensitive to whole-body motion and overturning). For example, an M113A1 personnel carrier, oriented so that one side faces the blast, will overturn at a peak static overpressure of about 27 psi delivered by a 1-kt weapon. However, overturning will occur at about 9 psi when the vehicle is subjected to a 100-kt detonation. Overturning is also very orientation dependent. The M113A1 that was oriented side-on to the blast and was overturned at 27 psi by a 1-kt weapon would require 50 psi to overturn if oriented end-on to the same blast.

(3) *INR*. Gamma-ray penetration of materials and interaction with atoms produce critical effects in semiconductors and other electronic equipment. Pulse-induced currents can trigger semiconductor switches and cause large transients flowing through electronic circuits. Power supplies are particularly susceptible to these effects. In some semiconductor devices, gamma-radiation-induced currents can induce "latchup," in which circuits are locked in a condition that allows larger than desired currents to pass. These currents continue until the external power source is removed. Burnout, memory loss, or an inability to respond

to signals may result. Stored digital data, particularly in semiconductor random-access memories, can be scrambled by the prompt gamma-ray environment.

In electronic equipment, the gamma-ray intensity is measured in centigrays (cGy) (Si), which is somewhat different than cGy (tissue). A cGy (Si) for material is the amount of radiation which will deposit 100 ergs of energy per gram in silicon. To describe the prompt gamma-ray environment, the rate of deposition may be the important factor, so cGy (Si) per second is used; for this reason, this environment is often termed the "dose rate."

The direct intersection of gamma rays with a system can also produce SGEMP. The resulting fields and current depend upon the size, shape, structure, and composition of the system. For atmospheric nuclear bursts, SGEMP matters only within limited ranges (a few kilometers), typically for systems that can withstand the other nuclear environments. For a near-surface tactical burst, SGEMP can have a significant effect on command, control, communications, computer, and intelligence systems.

Equipments are also affected by the longer-term gamma rays (total dose) and the pulse of neutrons and may produce the residual radiation (fallout) as well. The principal effects from these environments are the permanent changes in electronics and in optical materials.

Neutrons incident on a material (the unit of neutron exposure is fluence, expressed in neutrons per square centimeter) can displace the material's atoms, changing molecular structure and permanently changing the electrical or optical properties of the material. The greatest concern is for changes in silicon semiconductor devices, such as degradation of transistor gain or changes in saturation voltages.

The total dose ionization in the material is characterized by the moving of positive and negative charges. In moving, these charges can get stuck (or trapped) at other normal sites, changing a material's electrical or optical properties. For example, a window may darken, or a microprocessor may fail to perform.

Gamma rays and neutrons can also change the optical absorption properties in optical fibers. Even a small loss of transmissivity (darkening) in long fiber-optic cables can become a significant problem, since the amount of light that can be transmitted by the cable drops.

Collectively, these effects are referred to as transient radiation effects on electronics (TREE). However, the term "transient" is misleading—from the interest of the Army, neither the radiation nor the effects are transient. The Army has an extensive base of experience for estimating TREEs and developing means to counter them.

Whether the system will be affected by a particular radiation exposure depends on its sensitivity, the circuit application, exposure levels, device type, and the process used to manufacture the device. Each case must be evaluated individually by the material developer.

The environment associated with the most susceptible components might be expected to occur as far as 3–4 km from a 10-kt burst and at 1 km or less for the least susceptible components.

Neutron and total gamma-dose effects can degrade electronic operations. Also, gamma-ray pulse effects can cause momentary "switch on" of all electronic semiconductor devices in a system. Of these effects on Army tactical systems, total dose creates the most problems with modern electronics. As man accumulates radiation in his body, electronics accumulate the gamma dose first from the prompt radiation pulse emitted in the first minute after detonation, and then further doses from fallout. This accumulation of radiation progressively degrades operation. Man may be able to continue to operate for some time after receiving the lethal dose; however, electronics degrade and fail the moment a "lethal" dose is reached.

The electronic designer can select specific electronic components to avoid total dose problems—but this is a deliberate decision for each part. Each decision should be based on experimental data before the design is started. For equipment employing the latest electronic technology, the total dose response may be unknown, and it may fail at one-fifth the dose that kills the soldier carrying it.

In some instances, the gamma-ray pulse rate can cause components to switch on. Here the TREE is compounded by source region EMP. In many cases, the electronic design can solve the problem; current limiting resisters at the appropriate places will prevent damage and reduce the problem to one of resetting or reinitializing the system.

Neutrons need not be a problem, provided parts are carefully selected as design is initiated. Generally, modern electronics are not susceptible to damage at the neutron levels seen by Army tactical systems.

(4) *EMP*. EMP does not pose a direct threat to human life. However, it is of great indirect consequence because it can threaten electronic systems critical in a war. For detonations above the atmosphere, EMP is the only environment that threatens most of our land-based tactical Army systems, although other nonmaterial effects may be observed affecting radio and radar transmissions.

The effects of EMP are thoroughly documented from test results of the 1950s. Frequent EMP-related malfunctions with electronic recording instruments have occurred. In 1962, a high-altitude burst over Johnston Island created many effects on the electronic power grid over 800 miles away in Hawaii. Burglar alarms were set off and power-line circuit breakers tripped. In 1974, during a simulated EMP test in Polk City, FL, a computer memory was erased.

Test data have clearly established that EMP can have disastrous effects on electronics. Before discussing these effects, it is important first to briefly discuss how EMP couples to electronic equipment and second to suggest some mitigation procedures that can be used to prevent EMP from entering systems. Even in a storage or shut-down mode, some equipment can still be vulnerable to EMP.

All connections or openings in equipment and any surface material that does not stop EMR is a potential entry point for EMP. Antennas, even unintended antennas such as pipes, ventilation ducts, or holes, are entry points into electronic equipment for EMP.

The actual amount of energy that is transferred depends upon the equipment and conductor orientation with respect to the EMP source and the actual EMP frequency amplitude. Further, the subsystem of concern need not be directly coupled to the entry point. The collector can create EM fields that can, in turn, cause damage to equipment vulnerable to the EM fields, such as computer memories.

All of our common systems have potential EMP coupling sources. For example, the metal skin on aircraft and helicopters can diffuse EMP-induced currents and provide some protection; however, there is an increasing use of composite panels which may be transparent to EMP. Penetration points include breaks (intentional or unintentional) in the shield (e.g., antennas and transceivers, windows for pilot visibility, and openings for the movement of control surfaces and landing gears). In locations where cables are next to openings or joints and seams, coupling opportunities exist with the cabling running inside the aircraft. The amplitude and frequency of EMP energy that can be coupled into the equipment on board is, in part, a function of the aircraft size.

Since missiles are generally smaller than aircraft, EMP-induced currents on the missile skin tend to be smaller and at higher frequencies than for aircraft. However, in the prelaunch mode, the transporter, erector, launcher, and the associated electrical cables become the dominant coupling source. Penetration opportunities exist along cable raceways, hydraulic lines, data lines, and seams. Nonmetallic panels also offer openings to EMP.

Ground vehicles are usually metallic and of substantial thickness so that current diffusion is not a significant concern. However, electronic components or subsystems may be mounted on the outside of the vehicle chassis where direct exposure may produce large effects. Further, the seams and openings may expose electronic components within an engine compartment.

Electronic equipment mounted within an unhardened electronic signal shelter can be protected, but still have numerous potential penetration points. This is particularly true when direct connections to the electronic equipment exist, as with antennas or power cables, where large EMP currents and voltages can couple into the system. (Some electronics may be in a metallic structure, such as a maintenance vehicle, that was not designed to serve as an electronic shelter.) Also, vehicles that are electrically interconnected may appear as very large effective antennas and couple large and complex current flows.

Without penetration protection, coupled EMP currents and voltages can interact with a system's electronics and cause a number of events to occur. There is approximately a 10% probability of unprotected electronic equipment damage when the peak EM field is as low as 5 kV/m. At 25 kV/m the probability increases to 90%.

Upset from low-level EMP-induced voltage can range from minor effects, such as bursts of errors, extraneous signals, or "bit flips" in memory, to circuit logic changes that require operator intervention for recovery, to a more significant upset effect, latchup. In latchup, a circuit is "locked" into an unusual condition from which it cannot exit without being powered down and restarted. Such degradations can last from a fraction of a second to hours and in some cases cause permanent damage.

Permanent damage can occur directly from coupled EMP currents and voltages or indirectly by EMP-induced transient current paths between conductors. In essence, the system can receive a power overflow that produces "burnout" of components and memory sets, thereby disabling the equipment and requiring

repair or replacement. The components most susceptible to "burnout" in a system are solid-state semiconductor devices.

How sensitive are electronic components? All military systems with electronics can be vulnerable to EMP.

Solid-state components, computers, power supplies, and communications links are most susceptible. These failure levels can fall within the typical 50-kV/m threat environment.

The EMP-induced currents and voltages to produce systems upset are generally much less than those required for permanent damage. In addition, an increasing use is being made of digital systems with their associated higher upset susceptibility. Smaller components generally have lower burnout thresholds.

Pas filters are less sensitive than semiconductor devices. Relay solenoids, motor windings, and transformers are relatively hard.

5.3 EWD.

5.3.1 Detectability. ESM/RWR/ELINT receivers, acoustic detectors, and ADU/battlefield radars and FLIRS all utilize the detectability of the system to direct weapons or active/passive CM at the system or warn of its presence. They are looking for the RCS, RF, MMW, EM, microwave, acoustic, or IR signature of the Apache D or LBMMS. EWD has the capability to measure the signatures of actual helicopters and missiles in both field and laboratory environments. EWD has a requirement for LBA models of the RCS and IR signatures.

5.3.2 Lasers. A variety of lasers could be directed at the system with the intent of physically damaging it, incapacitating the crew, or degrading system performance. These effects could come from lasers used as battlefield expedient weapons to actual weapons designed for permanent damage. Lasers could also be targeted to detect system optics or to detect the complete system through the use of a laser infrared radar (LIDAR). EWD has had considerable experience at measuring the impact of low-energy lasers on Apache A.

5.3.3 RF Jammers. Jammers directed at the Apache D subsystems other than the missile, RFI, and FCR could degrade survivability. These could affect navigation, communication with the ground or other aircraft, and the combat identification system. The effect is to degrade operation in a combat environment generally affecting exposure to enemy fire. A single jammer would not be feasible due to the wide variety of requirements. To access the impact on the system, a variety of laboratory/field measurements, analysis, and combat simulations would be required.

5.3.4 Counter Survivability Suite. The Apache D has a survivability suite which is likely to be expanded upon deployment and expansion of the threat. A full suite might include an LWR, RWR, missile launch detector, IR and RF jammers, IR and RF CM, etc., and a processor that integrates the various parts of the suite. CM to the suite could include jammers to counter the various warning receivers and the launch detector. Assessment would require details of the suite and measurements of its subsystems.

5.3.5 Theoretical Analysis/SEMI. Detailed analyses of system schematics, transfer functions, and technical manuals are conducted to learn system operation and signal processing. From this RF modulation parameters are predicted for optimum susceptibility. Theoretical coupling analyses using user-oriented computer codes are conducted to predict RF energy transfer. A field coupling analysis is performed to predict the EMR parameters to which the system might respond and to develop an electromechanical transfer function of the control system. The field coupling effort includes such things as modeling the system's outside surface as a receiving antenna (e.g., monopole or an end-fed resonant dipole). The various potential coupling ports are also considered. This analysis results in identification of the EMR frequency(s) most likely to be coupled into the system electronics and a prediction of the most susceptible aspect and roll angles.

The Missile Sensitive Frequency Program (MSFP), Mautz Body of Revolution (MTZBOR), and tube are some of the programs used to conduct the theoretical coupling analyses:

(1) *MSFP*. MSFP models the characteristics of EM scattering by a thin-walled, closed cylinder which approximates a fat dipole. The output of this model is a collection of fundamental resonant frequencies and harmonics for optimized body mode coupling to the cylinder. Table 3 is an example of the output generated by MSFP in providing the fundamental and harmonic frequencies given the physical dimensions of the system under investigation.

Table 3. MSFP Output Example

Low (3 dB down) (MHz)	Center Frequency (MHz)	High (3 dB down) (MHz)
7.25	8.16	9.07
15.96	17.5	19.04
25.03	27.11	29.18
34.29	36.85	39.41
43.68	46.68	49.69
53.15	56.58	60.01
62.68	66.52	70.36
72.28	76.62	80.95
81.85	86.62	91.39
91.44	96.61	101.79
101.08	106.63	112.18
110.76	116.67	122.58
Length of aircraft	14.6300 meters	
Diameter of aircraft	1.5750 meters	
Aspect ratio (diameter/length)	0.1077	

(2) *MTZBOR*. This program computes the single frequency plane wave excited surface currents induced on a conducting body of revolution. Bodies of revolution are rotationally symmetric structures that approximate the enclosures of many practical systems such as missiles and aircraft fuselages (Figures 6 and 7).

The program computes the surface currents induced on a conducting body of revolution.

(3) *Tube*. This program analyzes the surface currents and interior electric fields of a thin-walled, finite, cylindrical conducting tube in the presence of a plane EM wave of arbitrary polarization and angle of incidence (Figure 8).

The program computes the calculated surface current density or electric field for a given set of input variables. The effect on surface current distribution of varying one variable (e.g., frequency, aspect angle, etc.) as a parameter is obtained by iterative mode runs.

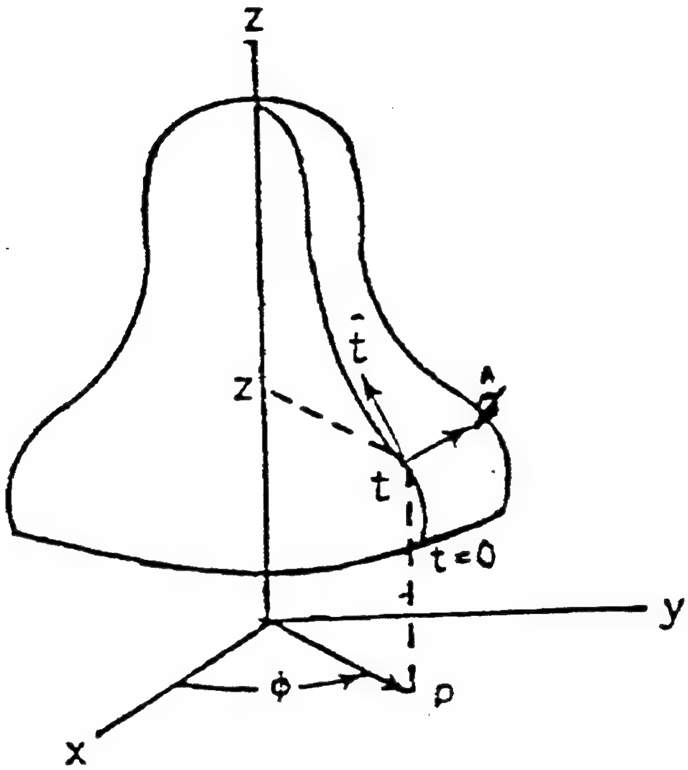

Figure 6. Body of revolution and coordinate system.

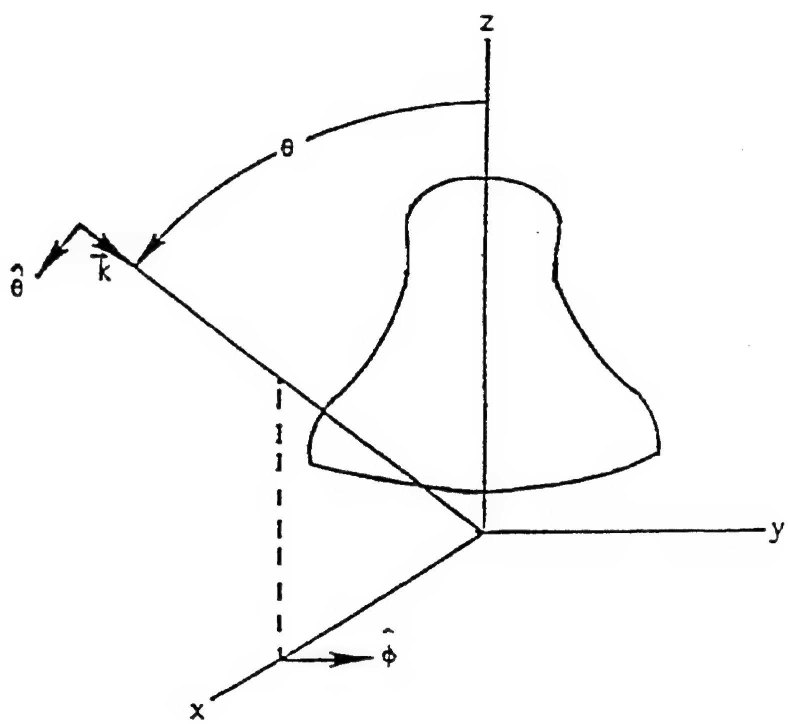

Figure 7. Plane wave excitation of a conducting body of revolution.

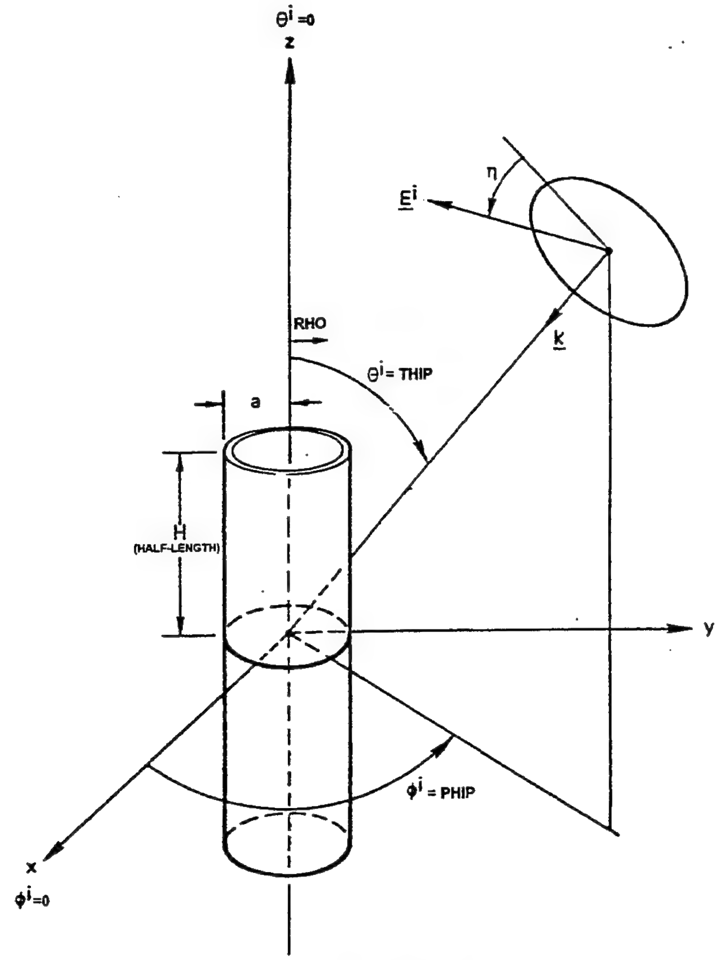

Figure 8. Tube geometry.

Once an EMR signal has been coupled into the system electronics, it may or may not affect overall performance. The electromechanical transfer function, which describes the various control loops, circuit gains, bandwidths, etc., provides an insight into potential ports of entry based on the location of high-gain preamplifiers and sensitive rectification circuits. The signal conditioning circuits (e.g., choppers, filters, and other bandwidth-limiting devices) are used to define the modulation parameters most likely to affect system performance. If this format is rather complex and difficult to emulate, a simpler format is also defined. Consideration is given to signals within the overall control system bandwidth, as well as higher frequency components which can pass through portions of the circuitry and then be rectified (possibly causing an erroneous bias buildup in the final control system).

Another parameter of significant interest is the system response time. This is the time required for the control system to respond to various stimuli and may vary depending on the point of interest in the

circuit. The system transfer function may also be used to aid in selecting the various investigation points used when performing the EM radiation susceptibility measurements. These analyses are vital to understanding the cause and effects of interference observed during the laboratory measurement phase.

Reiterating, the "target description coupling codes" that are currently in place at EWD for analyzing out-of-band or SEMI effects provide first/second-order results. They provide the investigator with better than "ball park" approximations to sensitive RFCM parameters that might induce system upset. However, although these calculated data are invaluable as a starting point, they do not provide the quality of data necessary if one is to draw final conclusions about a system's susceptibility, especially in the absence of measurements. These data must be continually validated with measurements to provide proof of a system's susceptibility/vulnerability to a SEMI environment.

The limitations on the aforementioned programs are such that special-purpose programs must be created and calculations that are labor-intensive and time-consuming have to be made. These efforts do not provide the accuracy and timeliness of results required for determining the RF effects on systems and components.

MSFP, for instance, is a program that has an aspect limitation. Sense and destroy armor (SADARM) is an example of a system that could be analyzed with the help of MSFP due to its squat aspect ratio. Programs that work with "odd-shaped" systems are required to be able to provide the type of accurate and uniform results that will feed the rest of the analytical process.

While tube calculates the surface currents on a simple cylinder, MTZBOR takes the sophistication one step further and allows for bodies of revolution symmetry. This is a very powerful tool in analyzing systems that can be approximated in such a matter.

Computational tools must be developed that have the capability to simulate or emulate complex nonsymmetrical systems in a user-friendly manner. These tools will be capable of being validated with sufficient measured data. They will also provide higher order effects data such that more definitive conclusions can be made about a system's susceptibility/vulnerability based on the results of these target description coupling code computations.

6. REQUIRED RESOLUTION OF THE TARGET DESCRIPTION FOR THE ANALYSIS OF THREATS

To meet the required resolution of the target description for the analysis of threats, many analytical tools must be developed, and the hinge pin of these tools is the BRL-CAD target description,. The resolution and/or the granularity of the target description is anticipated to be the limiting factor in future analysis. It is also understood that by increasing the resolution and complexity of a target description, the computational requirements needed to perform an analysis, using these target descriptions, will also be increased.

6.1 BVLD. To accomplish the BVLD goals (i.e., to determine ballistic vulnerability, lethality, and survivability; reduce vulnerability; and enhance the survivability and lethality of all U.S. Army systems; and provide timely, accurate analysis to decision makers), one must analyze KE (AP, API) and a combination of KE (fragments) and blast (HE, HEI). In addition, both the AP and the HE have incendiary versions (API and HEI), where the incendiary effect combines with the KE effect. The effect these four damage mechanisms have on system functionality is the same effect the chemical and biological agents will have on system functionality. For example, the loss of crew due to ballistic damage will have the same effect on the system's ability to move as will the chemical/biological case; similar cases can be made for other functional requirements of the system. The basic premise is that whether it is ballistic or chemical (or both), the effects on the aircraft's functionality are the same. Although chemical/biological agents do not normally cause structural damage to ground systems, the effect of aircraft components sustaining chemical/biological agent damage can result in eventual loss of the aircraft due to hard forced landing or, possibly, a crash.

The effects of ballistics on sights, windows, windscreens, canopies, and view ports can be the same as chemical/biological effects. A cracked or partially shattered piece of glass/plastic glass will produce the same degradation as a chemical film on that glass, therefore producing the inability to identify, inability to detect, etc. This relationship can be found in the way the physics is described within the general V/L taxonomy where the way the component became damaged is no longer of interest when mapping to system remaining capabilities.

6.2. The CBNED. The goal of the CBNED is to be able to perform objective analysis of the survivability/vulnerability and effectiveness of U.S. Army and select foreign combat, combat support, and

combat service support systems to chemical, biological, and nuclear weapons effects to include degradation by smoke, obscurants, and atmospheric effects.

6.2.1 Chemical and Biological Agents. In a CB attack, the individual soldiers, or local inhabitants, are generally the intended targets. The loss of a vehicle's crew amounts to a total loss of mobility, main armament, and target acquisition capabilities. These losses may occur when a CB agent is encountered, and these losses may occur with very minimal, or no, structural damage to the vehicle.

Some of the important aspects that must be considered in a CB scenario is the vulnerability or survivability of the crew area of the vehicle and the vehicle's optics. To determine if an agent can infiltrate a crew compartment, the composition of the seals which protect this compartment becomes vital. Knowledge of the composition of the optics (this includes all sights, windows, canopies, and view ports) becomes necessary if the analysis is to be able to predict whether the optics will be hazed, crazed, or otherwise affected.

Chemical agents can also affect electronic components and circuit boards. Agents may also be used to clog intake filters or cause engine failures through other means. It is necessary that the materials that make up the different components of a target description be identified to the greatest extent possible. Composite materials are currently being used to a great extent in flight frame construction. Also MGED currently has a material code for only one composite—fiberglass (per Geometric Solutions, Inc., Material Code Chart for MGED, vulnerability analysis for surface targets [VAST], and computerized vulnerability-area and repair-time [COVART] [Reed, Murray, and Cericole 1991). It should be noted that MGED, and BRL-CAD for that matter, were designed with only ballistic threats in mind. And when considering a ballistic threat, the variations between composite A and B make no difference.

When dealing with a chemical threat, the composition of the different components of a target description must be known. The changes in physical properties of these materials when exposed to CB agents will determine the damaged components in Level 2 of the taxonomy. The changes in physical properties is the O1,2 mapping.

6.2.2 Obscurants. The potential result of encountering a smoke or obscurant on the battlefield is the degradation of the transport medium through which the target signature must pass. Smoke and obscurants can affect signatures by either absorbing or scattering both the incident and reflective energy from an

illuminated target. As stated earlier different smokes and obscurants affect different areas of the EM spectrum. The radar and optical tools currently available within BRL-CAD would greatly benefit from the introduction of obscurants and smoke into the CAD package. This would provide an analytical means for performing trade-off analyses between sensors and obscurants.

The introduction of smoke and obscurant clouds into the BRL-CAD package would allow quantitative analyses to be performed on the acquisition reduction caused by different smokes and obscurants. This is the O2,3 mapping, the resultant capability state due to the smoke or obscurant. Radiance may not affect a target signature directly but can modify the clutter levels in a target/background scene. This requires a tool to introduce a number and intensity of radiant sources comparable to the expected threats, as scene modifiers.

6.2.3 Nuclear. The effects of the different nuclear environments upon systems vary greatly. Because of this variation, each of the environments is addressed separately.

(1) *Thermal.* The results seen at the system level due to thermal effects are the charring and melting of materials. Thermal effects are seen on those materials in a line of sight from the nuclear event. Once this list of target description elements has been generated, the thermal effects on these elements needs to be determined. The thermal effects on the target are considered in the O1,2 physics mappings, changes in the physical properties of elements of a target description. More materials are required in MGED than the 40 which are currently available (see Reed, Murray, and Cericole [1991]).

(2) *Blast.* The results seen at the system level due to blast effects are overturning, slipping, and crushing. Target description resolution for analysis of blast effects is required only down to the "box" or line replaceable unit (LRU) level (e.g., computer, radio, etc.). Requirements here include the calculation of masses and centers of gravity to determine overturn and slipping. It is felt that the resolution currently used meets the requirements for a blast analyses.

(3) *INR.* The results seen at the system level due to INR are circuit upset, latchup, and semiconductor device burnout due to gamma ray and neutron interaction with semiconductors. When doing on INR analysis, the geometric position of elements within the target description become unimportant. This is not an effective shielding technique available to protect a vehicle from INR. Simple element (i.e., semiconductor chips, resistors, etc.) identification lists are required for INR analysis. These lists are

checked against existing databases to determine the effect of the INR environment on that element of the target.

The required resolution required for this type of analysis is down to that of an LRU for which the exact element or component makeup is known.

(4) *EMP*. The results seen at the system level due to EMP are semiconductor burnout and transient upset. These effects are achieved due to energy being coupled to the system via cables, antennas, apertures, etc. A high amount of detail is required for EMP analysis, and elements down to the semiconductor chip or individual resistor need to be identified if they are not shielded. Breaks in materials, shields, Faraday cages, etc., are required to determine how the pulse is conducted around and through the target. For nonshielded items, a resolution of 200 µm (2×10^{-4} meters) has been estimated as the requirement.

6.3 <u>The EWD</u>. Table 4 identifies the required resolution of the target needed to perform an EWVA on the survivability of Apache D and LBMMS.

The "target description coupling codes" currently in place at EWD for analyzing out-of-band or SEMI effects provide first-/second-order results. They provide the investigator with better than "ballpark" approximations to sensitive RFCM parameters that might induce system upset. These data provide a good starting point for the analysis and linking the theoretical results with measurements.

The resolution required for EWD to provide the required SEMI effects data for analysis is such that the system physical dimensions blueprints must be down to the 1/32 in as a nominal figure. The more accurate the blueprint, the more accurate the secondary and tertiary coupling frequency calculations will be. The schematics must be down to the integrated circuit (IC) and, in some cases, below the IC level.

7. SUMMARY/CONCLUSIONS/RECOMMENDATIONS

7.1 <u>General</u>. The most basic recommendation one can make from this exercise is to prepare the target description as detailed as the intended system. One consideration is to create a target (down to its frog hair) and group it differently within the graphics editor with respect to each division's needs. For instance, create a target down to the nth detail and before its release have an analyst from each division

Table 4. Target Description Resolution

Class of CM	Resolution Requirement
SEMI	Mechanical, electrical drawings of all subsystems showing location and interconnection of all components.
Detectability	RCS - Mechanical drawings of exterior of system to 1/4 wavelength resolution. Need to verify with measurements. IR - Similar drawing and measurements at the wavelength of interest. Heat budget at surface of target. MMW - Need system specifications and antenna patterns to calculate.
Laser	Details of optical, laser, IR sensors through component level required to assess in-band damage. Information on exterior of sensors and aircraft materials and the susceptibility to out-of-band laser damage required.
RF Jammers	BCIS/IFF - Require hardware to measure. Need antenna patterns for when on Apache. Need electronic description and specification of system.

quantify the items needed for his/her respective division (i.e., BVLD parts, EWD parts, and CBNED parts). In the past, the ballistic portion has been dealing with vulnerable areas and probabilities of kill and has not been concerned with the intricate detail of targets. Following the taxonomy for V/L processes and implementing Degraded States Vulnerability Methodology (DSVM) is one way of honing our vulnerability skills. Shared target descriptions will allow comparability between BVLD, CBNED, and EWD, which was previously not available. Now that one has a methodology and code to handle such detail, the results of the analyses will be much more accurate and will be measurable and observable on the experimentation range. In addition, one should take the time to not only have an appropriate target description but also have state-of-the-art tools in which to evaluate them. In the past, one would have to model fuel, hydraulic, and oil lines slightly larger than the original size. Since the latest and only interrogation technique, shotlining, does not possess any dimensions, the need to "oversize" the lines was implemented in order to account for a tumbling fragment or projectile. This is a shortcoming in the analytical techniques used by the vulnerability community. Therefore, it is recommended that shotlines be upgraded to include a user-definable dimension (i.e., projectile diameter or fragment shape factor). This improvement will allow one to model the "real world" within the target description to yield a higher quality product.

Reiterating, the "target description coupling codes" that are currently in place at EWD for analyzing out-of-band or SEMI effects provide first-/second-order results. They provide the investigator with better than "ballpark" approximations to sensitive RFCM parameters that might induce system upset. Although these calculated data are invaluable as a starting point, they do not provide the quality of data necessary if one is to draw final conclusions about a system's susceptibility, especially in the absence of measurements.

Computational tools that have the capability to simulate or emulate complex, nonsymmetrical systems in a user-friendly manner must be developed. These tools should also be able to be validated. High-order effects are required to be output from these tools to enable conclusions to be made about a system's susceptibility/vulnerability based on target description coupling code computations.

7.2 Recommended Target Description Granularity. Based on previous discussions, Table 5 presents the recommended target description granularities across all of the threats of concern to SLAD.

Table 5. Required Granularity Across Threats of Concern to SLAD

Threat		Required Granularity
Ballistic		Details of penetrator, encounter geometry; target materials, thickness, densities.
Chemical		Details of internals of the LRU[a] (e.g., materials, cracks, fans) and material properties (e.g., tensile strength, solubility).[b]
Biological		Similar to chemical. Main concern is threat to personnel.
Obscurants		Similar to chemical. Plus IR, radar signature properties.
Nuclear	EMP	Details down to the internals of the LRU (e.g., fans materials, cracks, shield breaks) down to 2 mm resolution.[b]
	Blast	Current ballistic resolution sufficient.
	Thermal	Details of materials which compose target components.[b]
	INR	Details of components within the LRU.[b]
Environmental		Similar to obscurants.
EW		Resolution down to ~0.8 mm for SEMI effects and 1/4 wavelength resolution for detectability work.[b]

[a] Line replaceable unit.
[b] Linked to external database.

The target description granularity required for chemical, EMP, thermal, INR, and EW analyses, as depicted previously, shows a link to an external (to BRL-CAD) database that details the LRU. For discussion purposes, consider a computer as an LRU. Within the target description, the internal components (e.g., circuit boards, power supplies) need to be specified. A circuit board can be constructed of a single region with a unique identification code. Within the target description, the individual semiconductor chips, resistors, capacitors, etc., are not required. What is required is a database external to the BRL-CAD target description for the LRU. In this database are all the specifications of the components that make up the LRU; these specifications are to include exact element lists of the components, as well as circuit diagrams of the components.

In an integrated analysis, the granularity of the target description is desired to be a function of the threat. With the introduction of time into the process structure (Ruth 1995) and the introduction of multiple threats into the analysis, the granularity of the target description used can be that appropriate to the threat being analyzed. This suggests that the granularity of the target description should be capable of change throughout the analysis.

7.3 Target Description Hierarchial Data Structure. It is recognized that by driving the granularity of the target descriptions higher and higher that the complexity of these descriptions is inversely affected. In a mathematical sense, it can be stated that the complexity of the target description (Comp) is inversely proportional to the granularity of the target description (Gran).

$$\mathrm{Comp} \propto \frac{1}{\mathrm{Gran}}.$$

In the past most target descriptions have been created with the upper-most region being given the name of "*all*". Underneath this global region were grouped the subsystems (as shown in Figure 9). These subsystems were themselves made up of grouped regions. These regions were constructed of the CAD primitives using the three combinational techniques of union, difference, and intersection. In the recommended structure, the ways in which the primitives are combined into regions and the way in which regions are grouped into more detailed regions remain unchanged. The techniques remain the same, what changes is what items are grouped into what regions and when are they grouped this way.

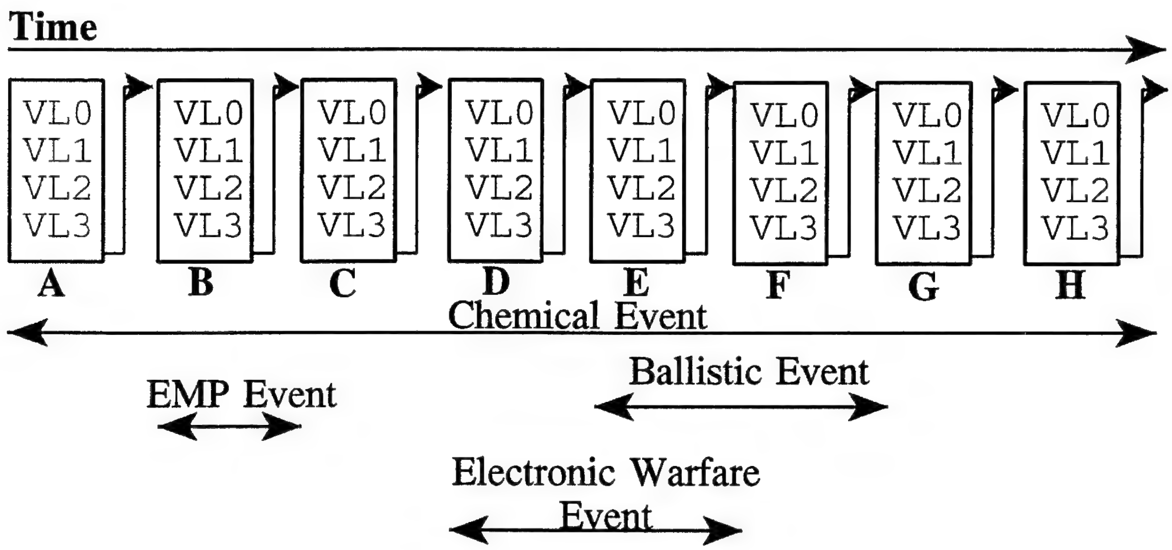

Figure 9. Introduction of time into an integrated analysis.

The concern also exists that as the complexity of the target description rises so will that of the time required to perform an analysis using these target descriptions. One thing that could be done to reduce the target description complexity during an integrated analysis is to structure the hierarchy of the target description around the separate threats. Figure 10 shows the fundamental hierarchy of a target description (Deitz and Applin 1993). The solids are combined through Boolean operations to form regions; these regions are then grouped into subsystems; and these subsystems are further grouped into systems. In this structure, the threat is not considered except when defining the basic solids (e.g., oversizing fluid lines to account for a tumbling fragment).

Figure 11 shows how this hierarchy might be used to structure a target description around the separate threats. This figure is depicting the need for higher granularity in a generic subsystem—in this case the LBA canopy—when dealing with the separate threats. It is recommended that all future target descriptions be constructed in this manner. It should also be noted that the capability of having a dynamic granularity built into the target description is of no benefit if the fault tress which will be used to perform the O2,3 mapping are not suitable to make use of this additional information. This introduces the concept of integrated fault trees, but this concept is outside the purview of this report.

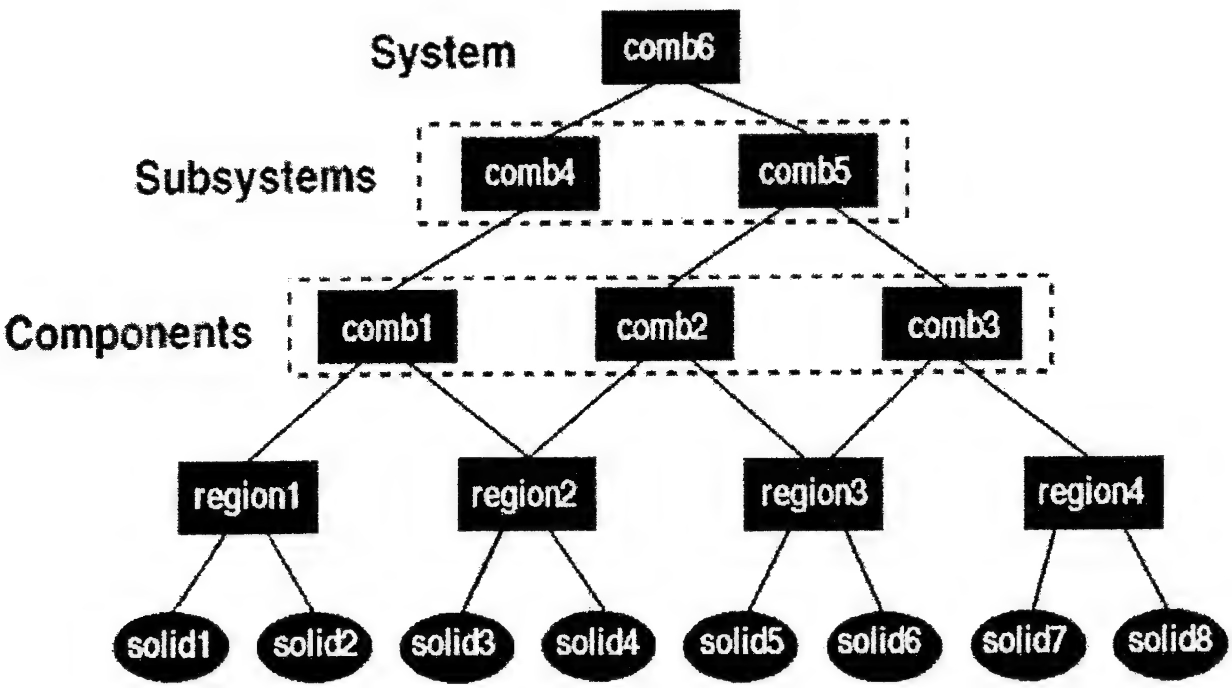

Figure 10. The fundamental BRL-CAD hierarchical data structure.

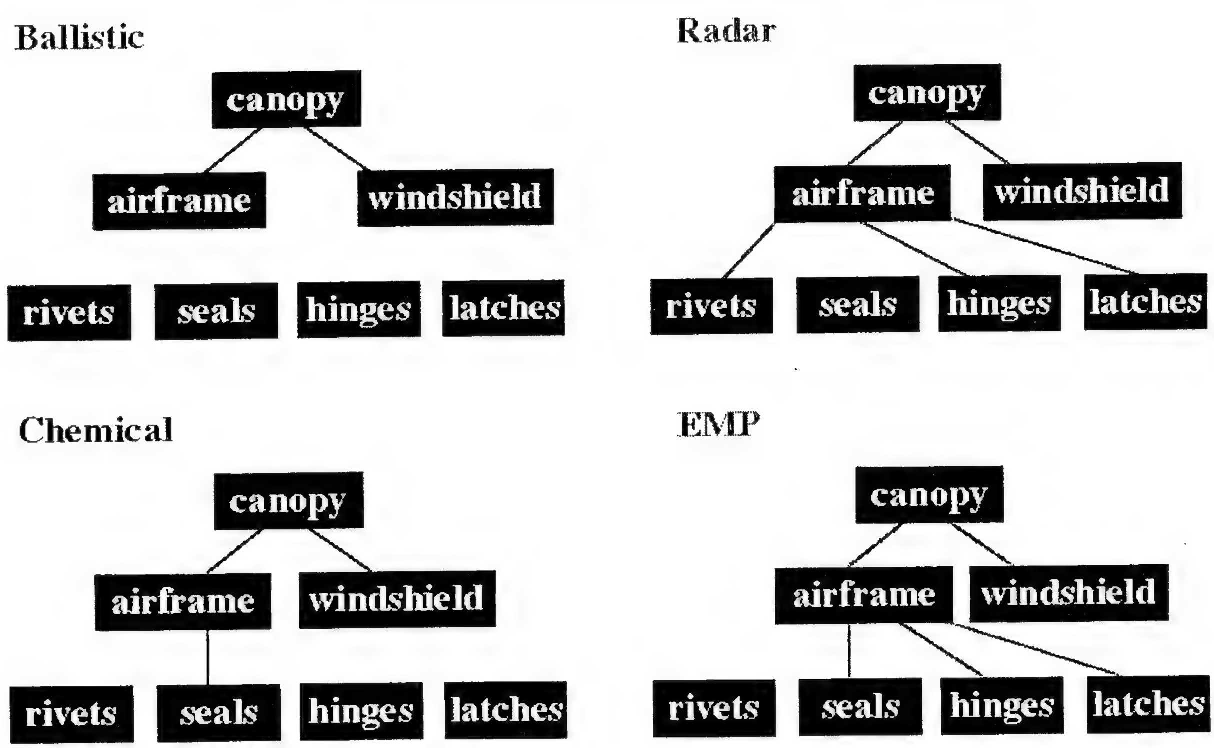

Figure 11. Threat-orientated BRL-CAD hierarchical data structure.

There are several way of achieving this structure within a *.g* file (the BRL-CAD binary geometry database file). The first is to simply construct several different versions of the target description under the separate headers identifying the threats (e.g., ballistic, radar, chemical, and EMP).

Another structuring technique worth considering is the use of pointers. Pointers, linked to the particular threat type, could be used to identify the bottom-level solids or low-level regions of interest to the particular threats.

Using the scheme laid out in Figure 8, time in an integrated analysis, and the structure techniques (shown in Figure 10), one can step through a possible integrated analysis being done on the LBA (shown in Figure 11). For discussion purposes, here we are only concerning ourselves with the canopy and its potential vulnerability to a chemical agent. The mast-mounted assembly and the rocket pods are more vulnerable to EW and ballistic threats, respectively. As the analysis follows the steps shown in Figure 9, the granularity of the description changes from event to event. As shown in Figure 10, as this granularity changes, subsystems (or LRUs) of interest change, and the databases external to the CAD target description are available with some of the "frog hair" details. In an analysis, information on the damage to the components is carried from one event to the next, as elements of a "*Meta-vector*," in terms of both the component-level damage and as the system capability state (Figure 1). The component-level damage is determined by the threat interacting with the target description, and the system capability state is determined by using the component-level damage as inputs to the system fault trees.

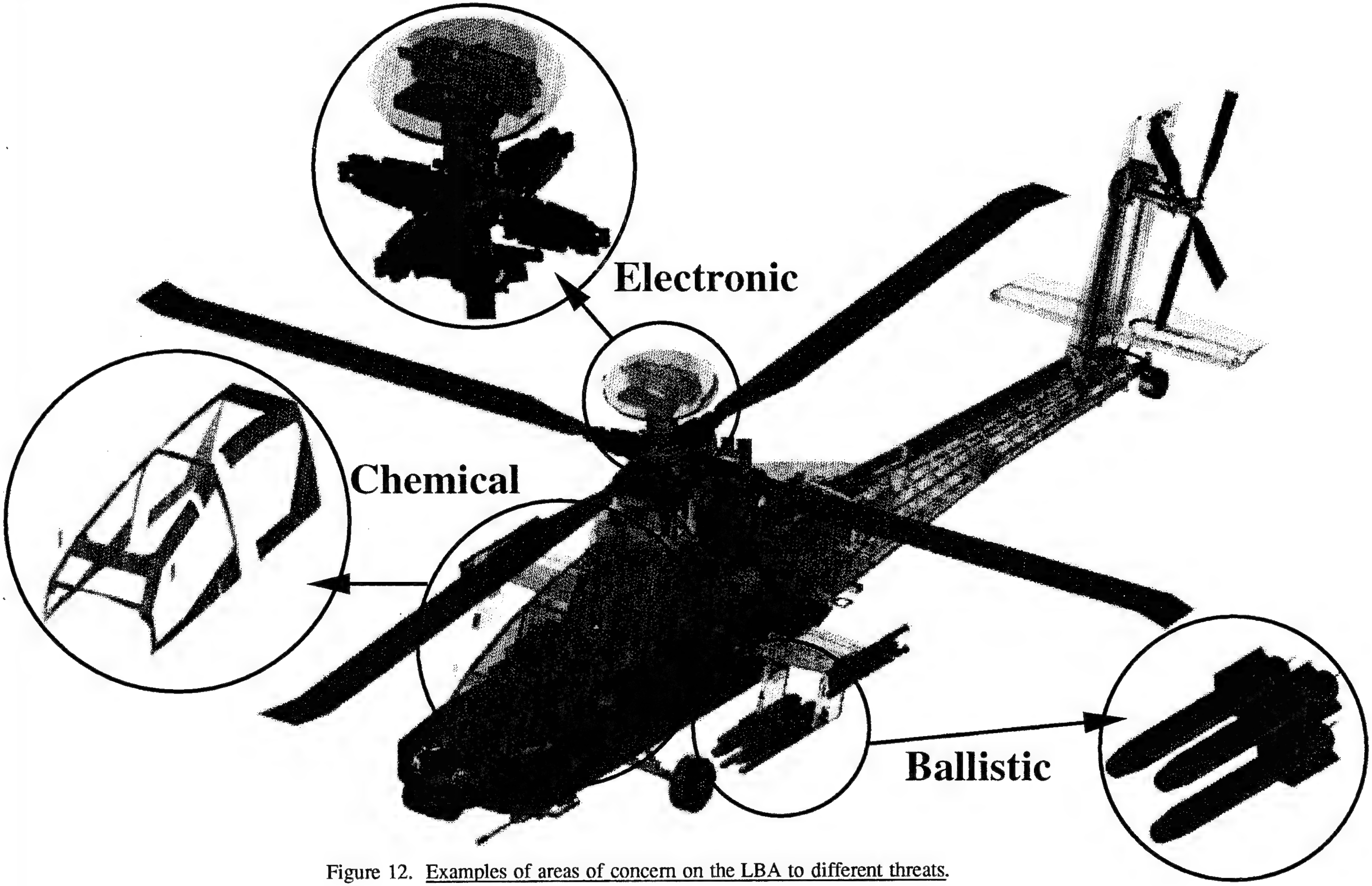

Figure 12. Examples of areas of concern on the LBA to different threats.

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8. REFERENCES

Ball, R. E. "The Fundamentals of Aircraft Combat Survivability Analysis and Design." AIAA Education Series, Naval Postgraduate School, Monterey, CA, 1985.

Deitz, P. H. "Comments by the BRL in Response to the Report of the Board on Army Science and Technology's Committee on Vulnerability." Unpublished paper, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1986.

Deitz, P. H., and K. A. Applin. "Practices and Standards in the Construction of BRL-CAD Target Descriptions." ARL-MR-103, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, September 1993.

Deitz, P. H., and A. Ozolins. "Computer Simulation of the Abrams Live-Fire Field Testing." BRL-MR-3755, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, May 1989.

Deitz, P. H., M. W. Starks, J. H. Smith, and A. Ozolins. "Current Simulation Methods in Military Systems Vulnerability Assessment." BRL-MR-3880, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, November 1990.

Ellis, C. A. "Vulnerability Analyst's Guide To Geometric Target Description." BRL-MR-4001, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, September 1992.

Klopcic, J. T., M. W. Starks, and J. N. Walbert. "A Taxonomy for the Vulnerability/Lethality Analysis Process." BRL-MR-3972, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, May 1992.

Moffett, D., and D. Alderson. "Nuclear Survivability Requirements Preparation Training Course Notebook." Prepared for Harry Diamond Laboratories by Kaman Sciences Corporation - Tempo Division, Alexandria, VA, December 1987.

Muuss, M. J. (Compiler). "The Ballistic Research Laboratory CAD Package Release 4.0, Volume IV." U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, December 1991.

Reed, H. J., E. L. Murray, and V. Cericole, Jr. "Beginning Modeler Techniques." Catalog Number: GSI-WCCAM-V1-E3, Geometric Solutions, Inc., Aberdeen, MD, July 1991.

Roach, L. K. "Fault Tree Analysis and Extensions of the V/L Process Structure." ARL-TR-149, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD June 1993.

Ruth, B. G. "A Nuclear Electromagnetic Pulse (EMP) Vulnerability/Lethality (V/L) Taxonomy With Focus on Component Assessment." ARL-TR-205, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, November 1994.

Ruth, B. G. "Introduction of Time into the V/L Process Structure." Briefing to Mr. Walt Hollis (DUSA/OR), Dr. Herb Fallon (SARD-Z), Dr. John Lyons (Dir. ARL), and Mr. John McCarthy (Dir. AMSAA), U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, 5 April 1995.

U.S. Army Chemical Research, Development, and Engineering Center. Internal Documentation Studies and Analysis Division, Aberdeen Proving Ground, MD, April 1986.

Walbert, J. N. "The Mathematical Structure of the Vulnerability Spaces." ARL-TR-634, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, November 1994.

Walbert, J. N., L. K. Roach, and M. D. Burdeshaw. "Current Directions in the Vulnerability/Lethality Process Structure." ARL-TR-296, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, October 1993.

zum Brunnen, R. L. "Introducing Chemical/Biological Effects Into the Ballistic Vulnerability/Lethality Taxonomy." ARL-TR-715, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, March 1995.

LIST OF ABBREVIATIONS

AA	-	antiaircraft
AAA	-	antiaircraft artillery
AAM	-	air-to-air missile
AB	-	Aviation Branch
ADU	-	Air Defense Unit
AIM	-	air-intercept missile
AP	-	armor piercing
APG	-	Aberdeen Proving Ground
API	-	air-piercing incendiary
ARL	-	Army Research Laboratory
ASB	-	Air Systems Branch
B	-	ball
BCIS	-	Battlefield Combat Identification System
BED	-	Battlefield Environment Directorate
BRL	-	Ballistic Research Laboratory
BRL-CAD	-	Ballistic Research Laboratory-Computer-Aided Design
BVLD	-	Ballistic Vulnerability/Lethality Division
CB	-	chemical/biological
CBNED	-	Chemical, Biological, Nuclear, and Environmental Effects Division
CE	-	communication electronics
cGy	-	centigrays
CM	-	countermeasures
COVART	-	computerized vulnerability-area and repair-time
CRDEC	-	Chemical Research, Development, and Engineering Center
CSG	-	constructive solid geometry
DSVM	-	Degraded States Vulnerability Methodology
ECCM	-	electric counter-countermeasure
ELINT	-	electronic intelligence
EM	-	electromagnetic
EMC	-	electromagnetic capability
EMI	-	electromagnetic interference

EMP	-	electromagnetic pulse
EMR	-	electromagnetic radiation
EO	-	electro-optical
ESM	-	electronic support measures
EW	-	electronic warfare
EWAB	-	Electronic Warfare Aviation Branch
EWD	-	Electronic Warfare Division
EWVA	-	Electronic Warfare Vulnerability Assessment
FCR	-	fire control radar
FLIRS	-	forward-looking infrared sensor
GPS	-	gunner's primary sight
HD	-	mustard (gas)
HE	-	high explosive
HEI	-	high-explosive incendiary
HF	-	high frequency
HP	-	high power
HPL	-	high-power laser
HPM	-	high-power microwave
I-T	-	incendiary-tracer
IC	-	integrated circuit
ID	-	identification
IFF	-	identification, friend or foe
INR	-	initial nuclear radiation
IR	-	infrared
KE	-	kinetic energy
LABCOM	-	Laboratory Command
LBA	-	Longbow Apache
LBMMS	-	Longbow Modular Missile System
LIDAR	-	laser infrared radar
LOF	-	loss of function
LRU	-	line replaceable unit
LWR	-	laser warning receiver
MGED	-	Multidevice Graphics EDitor

MMW	-	multimeter wave
MOPP	-	mission-oriented protective posture
MSFP	-	Missile Sensitive Frequency Program
MTZBOR	-	Mautz Body of Revolution
PM	-	project manager
PMO	-	project managers' office
RCS	-	radar cross section
RF	-	radio frequency
RFCM	-	radio-frequency countermeasure
RFI	-	radio frequency interferometer
RPV	-	remotely powered vehicle
RWR	-	radar warning receiver
SADARM	-	sense-and-destroy armor
SAM	-	surface-to-air missile
SEMI	-	special electromagnetic interference
SGEMP	-	system-generated electromagnetic pulse
SLAD	-	Survivability/Lethality Analysis Directorate
SLV	-	survivability, lethality, and vulnerability
SMSB	-	Survivability Modeling and Simulation Branch
T	-	tracer
TGD	-	thickened Soman
TREE	-	transient radiation effects on electronics
UHF	-	ultrahigh frequency
VAST	-	vulnerability analysis for surface targets
VEESS	-	vehicle engine exhaust systems
VHF	-	very high frequency
VL	-	vulnerability/lethality
WP	-	white phosphorous
WSMR	-	White Sands Missile Range

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